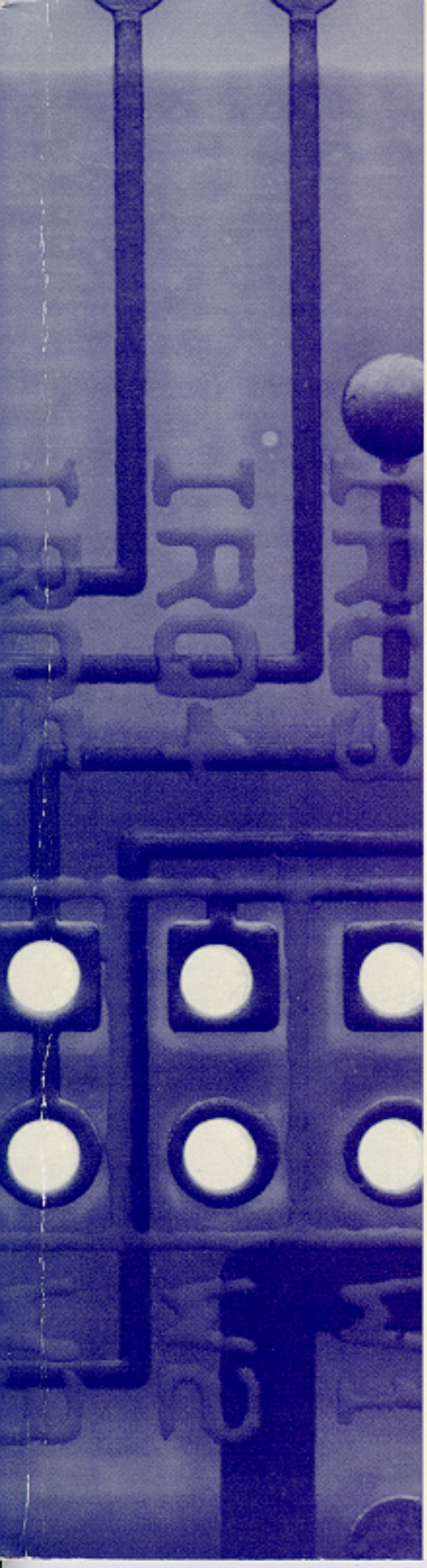

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SYMPOSIUM ON EVALUATING A PUBLIC-PRIVATE PARTNERSHIP: THE ADVANCED TECHNOLOGY PROGRAM

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THE TECHNOLOGY TRANSFER SOCIETY

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Symposium Overview

Rosalie T. Ruegg

This collection of papers relates to the evaluation of the Advanced Technology Program (ATP), the nation's civilian technology program charged with improving the competitiveness of U.S. businesses. The program accomplishes its mission by sharing the costs with industry of particularly challenging research projects that are expected to accelerate the development and commercialization of enabling technologies with strong potential for generating broad-based benefits to the nation.

The Economic Assessment Office (EAO) of the Advanced Technology Program seeks to measure the economic impacts of ATP's funding of high-risk, enabling technologies, and also to increase understanding of underlying relationships between technological change and economic phenomena so as to further the ability of the program to achieve its mission. To this end, the EAO compiles data, conducts economic studies, and commissions studies by outside research organizations and economists on the economic issues related to the projects it funds.

Evaluation has been practiced by the ATP from its inception, first as a management tool for the program and later to meet the mandated requirements of the Government Performance and Results Act (GPRA). As emphasized in a previous issue of the *Journal*, "Science and Technology (S&T) and Research and Development (R&D) programs are required as never before to regularly demonstrate the relevance and value added of their programs" (Jordon 1997, p. 3). Indeed, the ATP has met nearly continuous demand for measures of impact of the program since the day it was established. It is probably the most highly scrutinized program relative to its budget size of any government program to date. Yet the ATP funds long-term research projects, most of which are still in the research phase. It funds research underlying the development of enabling technologies which are expected to have benefits extending substantially beyond the direct ATP award recipient. Technology diffusion takes time under the best of circumstances, and tracking and measuring externalities, or spillover effects is complicated and difficult. Available evaluation tools are insufficient to that challenging task.

Despite inherent methodological and measurement challenges, the ATP's evaluation efforts are yielding improved methods and tools of analysis, early progress indicators, and projections of long-term impacts. ATP economists are tracking progress throughout the lives of the projects it funds and into the post-project period, compiling in the process an extensive database that is used for portfolio profiling and economic analysis. Through a cooperative arrangement with the National Bureau of Economic Research, the ATP commissions studies by leading economists working in the field of technological change, and these studies are extending the state of the art in the field.

This special issue of the *Journal of Technology Transfer* features some recent ATP evaluation studies. Some were performed by economists in ATP's Economic Assessment Office; some by academics under contract to the ATP; and one by a consulting firm. The papers presented are selected to illustrate a variety of evaluation issues. A number of other evaluative studies are underway.

For background and perspective, the first paper, by Rosalie Ruegg of the Advanced Technology Program, provides an overview of the ATP. It explains how the program operates, how it seeks to accomplish its mission, and what it has funded to date. The paper identifies the major components of ATP's evaluation program, and identifies research areas of particular interest to the evaluation program. Because the ATP is a much misunderstood program, this paper seeks to provide a basis for clearer understanding of its rationale and guiding principles.

The second paper, by Adam Jaffe of Brandeis University, reflects the importance to the ATP of generating and measuring economic spillovers. It illustrates with simple models how the benefits of ATP projects may extend beyond the direct ATP award recipients through market and knowledge spillover effects, and also discusses network spillovers. Jaffe recommends that the ATP fund projects whose expected social benefits are large and substantially exceed expected benefits to the awardees; guidance which the ATP seeks to follow. He also recommends that evaluation efforts include measures of spillover effects. This paper is presented early in the collection because it contributes to the understanding of later papers that refer to spillover effects.

The third paper, by Jeanne Powell of the ATP's Economic Assessment Office, presents and analyzes data from ATP's "Business Reporting System" to evaluate short-and-medium-term project effects. The paper describes ATP's principal data collection tool, and identifies a number of pathways through which ATP-funded technologies are generating impact. The enabling nature of the funded technologies is suggested by the many potential applications that have thus far been identified.

A paper which examines ATP's effects on the speed with which research is conducted and technology is commercialized is provided by Frances Laidlaw, formerly an industry consultant with the ATP and now a technology planner with Motorola. Laidlaw's paper questions not only whether, and by how much, the ATP accelerates research, but also the value of acceleration; whether saving time during the research stage translates into saving time downstream; and whether project participants realize any time-related benefits outside the walls of the project. Accelera-

tion of technology development and commercialization is of keen interest because it is part of the ATP's mission, and is one of several ways that the ATP can affect economic outcomes of the projects it funds.

The fifth paper in the collection, by Albert Link, an economics professor at the University of North Carolina at Greensboro, investigates the effects on research efficiency of collaboration in an ATP-sponsored joint venture. The project in question aimed to advance dramatically the technical capabilities of makers of printing wiring boards which provide the backbone of electronics products. His work also examines early productivity effects resulting from the new technical capabilities.

In the sixth paper, researchers at CONSAD Research Corporation report on a detailed case analysis performed for another research joint venture sponsored by the ATP, this one on new dimensional control technology for discrete manufacturing. It analyzes the multiple impacts of the new technology applied in the automobile manufacturing sector, and uses a macroeconomic model to project national economic impacts resulting from quality improvements in vehicles made by U.S. producers.

The seventh paper examines special considerations in modeling the social benefits of medical technologies. Prepared by Andrew Wang, an economist in ATP's Economic Assessment Office, the paper is inspired by a study conducted by economists at the Research Triangle Institute that is nearing publication. That study develops a framework for evaluating ATP-funded medical technologies, and applies the framework to project preliminary estimates of private, social, and public expected net benefits of seven tissue engineering projects funded by the ATP. Wang's paper provides a thoughtful exposition of several of the key concepts employed by the RTI study to estimate spillover benefits to patients who receive more effective, less painful, or less costly treatments as a result of the new tissue engineering technologies.

The last paper in the collection, by ATP economist Connie Chang, signals ATP's interest in counterpart programs to the ATP that are operated in most other industrialized countries. She shows similarities and differences in the programs by dissecting their design features. The ATP requires a detailed understanding of these other programs in order to take advantage of their evaluation programs in terms of the implications for the ATP. This understanding is also needed by the ATP to implement its Congressionally required evaluation of eligibility of U.S. subsidiaries of foreign-owned companies to participate in the ATP.

Many additional evaluation studies of the ATP are currently underway on a variety of topics. Most of this work will be reported in ATP publications, as well as in journals such as this. ATP welcomes comments and advice from the evaluation community on ways to improve the modeling and analysis of economic benefits from the advanced technologies it funds.

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Rosalie T. Ruegg
Special Issue Editor
Director, Economic Assessment Office
Advanced Technology Program

Reference

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The Advanced Technology Program, Its Evaluation Plan, and Progress In Implementation*

Rosalie T. Ruegg
Advanced Technology Program, National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Gaithersburg, MD 20899

Abstract

The Advanced Technology Program (ATP) partners with U.S. businesses in high-risk research to develop enabling technologies with strong potential for economic benefits to the nation. Universities, nonprofit research laboratories, and firms of all sizes participate in ATP-funded projects. ATP's evaluation effort seeks not only to measure the impacts of the technology development projects it funds, but also to understand the underlying relationships among research, technological change, and economic impact, and to provide feedback to the program to increase its broad-based benefits. Evaluation activities encompass developing models, conducting surveys, compiling databases, conducting micro- and macro-economic case studies, and performing statistical and econometric analyses. Program metrics include private rates of return, social rates of return, and public rates of return—the social-rate-of-return component attributable to the ATP. Topics of special interest, in addition to performance metrics, include spillover pathways, benefits and costs of collaboration, financing issues, and new models of impact assessment.

Overview of the ATP

To accomplish its mission, the ATP partners with U.S. businesses of all sizes in high-risk scientific research to develop enabling technologies with strong potential for broad-based economic benefits. ATP's focus is on technologies that offer, in civilian applications, the potential for substantial increases in productivity and competitiveness of firms, provide consumers with new, better, and lower-cost products and services, and increase high-wage employment in the U.S.

The multi-year ATP awards are made both to individual companies and to joint research ventures—comprised of two or more companies, often in combination with universities and nonprofit research laboratories. Most of the single-company awards actually resemble joint ventures in their involvement of other organizations. But the single-company awards are limited to $2 million and three years, while the joint-venture projects have no mandated limit on the amount of award, and their period of performance is limited to five years instead of three.

ATP awards are made through fair and rigorous competitions. The ATP held its first competition for awards in 1990, and has held a total of 30 competitions through 1997. Seven of the competitions—one each year—were "General Competitions," which are open to all technologies and applicants. The remainder were "Focused Program Competitions," through which, beginning in 1994, ATP has funded suites of related projects to achieve pre-identified sets of technological and economic goals developed in concert with industry. The General Competitions allow the ATP to cast a wide net and fund a wide array of good ideas. The Focused Competitions enable the ATP to deepen its funding to address larger problems and opportunities requiring concentrated, coordinated efforts.

From 1990 through 1997, the ATP made multi-year awards for a total of 352 projects, including over 100 joint ventures, and involving more than 800 participants (not including the many subcontractors and informal partners and collaborators that participate in many of the projects). These projects entail approximately $2.3 billion of research, of which industry committed slightly more than half, and ATP the remainder. Some of the earlier funded projects are now completed and an increasing number of them are moving into the commercialization phase. Most of the funded projects at this time are still in the research phase, reflecting the fact that the program's budget permitted more projects to be funded in the latter half of the 1990s than during the early years.

A rigorous peer review process is used to select all awards. Panels of technical, business, and economic experts carry out evaluations to assess the technical and economic merit of applicant proposals. Selection criteria include the potential of the research to contribute signifi-

*The author benefited from the helpful comments of Maryellen Kelley and Brian Belanger, both of the National Institute of Standards and Technology. The paper is drawn in part from a paper presented by the author at the 7th International Forum on Technology Management last fall (Ruegg 1997), and in part from a guide she prepared for evaluation researchers (Ruegg 1996).

cantly to the scientific and technical knowledge base of the country; the potential of the technology to generate broad-based benefits to the nation and the difference ATP funding would make to the effort; the proposed pathways to market and to broader diffusion; the commitment of the proposers to follow through with future development of products and processes if they are successful in overcoming the challenging technical barriers addressed in their ATP research project; the organizational structure of the project, and its management plan; and the proposer's experience, qualifications, and resources.

The ATP relies on the presence of expected private returns to induce companies to be willing to plan, propose, and cost-share research with the ATP, and, if the research is successful in overcoming the technical hurdles, to pursue commercial development of the new technology with private capital. To the many proposals it receives from companies, the ATP applies its criteria to identify which are expected to accomplish ATP's public-interest mission and objectives. It selects for award projects whose potential social rate of return (the return to the nation) is expected to far exceed the private rate of return on investment, and for which the private sector is unable without ATP assistance either to do the project at all, or to do it within the critical time frame, scale, or scope necessary to realize the social benefit potential.

The ATP is *not* a customer for the results of the technology development projects it funds. The ultimate outcomes are the results of the interplay of demand and supply forces in the marketplace. For this reason, the ATP is concerned not only with the benefits potential of the technologies from a hypothetical standpoint, but also from a very practical standpoint in terms of the proposers' ability, commitment, and plans actually to bring the technology into use in a timely way.

The ATP is *not* a funder of streams of basic research in the traditional mode of the U.S. National Science Foundation. It is NOT a procurer of mission-related applied research in the mode of the U.S. Defense Department and the U.S. Department of Energy. It funds research, not product development. It operates in the middle ground between basic research and product development.

Having industry conceive, propose, conduct, and cost-share the projects keeps them anchored in the applied world, oriented towards commercial potential, and run with attention to efficiency. Having highly qualified research scientists plan and conduct the research helps to extend the nation's scientific and technical knowledge base by taking on cutting-edge research with a reasonable level of feasibility. And funding only those emerging and enabling technologies which promise large benefits beyond the direct funding recipients, and which require ATP assistance to happen, ensures that the public interest is served. As expressed by Spender, ". . . by focusing on cost-sharing R&D within broadly conceived programs which are anticipated to have major public goods consequences, ATP harnesses private firms' resources to the public interest without seeking to outguess market forces" (Spender 1997, p. 46).

More information about the ATP is readily available at its web site, http://www.atp.nist.gov. There one can find summary statistics, application guidelines, selection criteria, project descriptions, participating organizations, funding amounts, and other information about the program. This information can, of course, also be obtained by contacting the ATP directly (1-800-ATP-Fund).

What and When to Measure

Because ATP's mission is economic in nature, its evaluation emphasizes economic impacts of the program. But there are a number of sub-objectives and constraints to the program that condition the program and its evaluation. For example, in addition to providing economic benefits, projects must entail high-risk research. Hence, one aspect of the ATP's evaluation concerns the scientific and technical contributions of funded research. Because the research is high-risk, it is understood that not all projects will be fully successful. Only a fraction will likely accomplish **all** the goals—scientific knowledge creation, timely commercialization of products and processes, and widespread diffusion of the technology leading to large spillover benefits. Most will be at least partial successes given that scientific knowledge often is gained even from research failures. Many will likely yield a sufficient return to pay back their costs. A few likely will be "home runs."

Since accelerating the development and commercialization of technology is a program mission, ATP's evaluation tracks the degree of speed up of technology development and the rate of commercial progress of award recipients. It also investigates the economic value of accelerating technology development projects.

Since the program is for national benefit, the evaluation is concerned with generating and measuring spillover effects beyond the direct benefits to innovators—including market spillovers, knowledge spillovers, and network spillovers. It seeks to fund technology development projects for which the spillovers are large, as reflected in gaps between the resulting social rates of return and the private rates of return to the innovators.

Because the ATP is charged with promoting the formation of research joint ventures, collaborative research is another topic of particular interest for ATP's evaluation. The objectives and progress of the individual joint-venture members are tracked, as well as those of the overall entity. Efficiency issues, the internalization of spillover effects, and technology diffusion effects are examples of research topics of interest to the ATP that concern collaborations.

Because it is critically important to the realization of benefits from the program that the ATP make a net contribution to the nation's economy—leveraging rather than displacing private sources of capital—ATP's evaluation

seeks to measure the differential impacts attributable to the ATP, in addition to the overall impact of projects and groups of projects. With- and without-ATP scenarios are posed to help get at the effects attributable to the ATP. This entails the use of counterfactuals and the attendant uncertainties thereof.

Overview of ATP's Evaluation Program

The ATP initiated evaluation at the outset of the program, first, to develop a management tool to make the program better meet its mission and operate more efficiently; and, second, to meet the many external requirements and requests for ATP program results. Demands for performance measures for the ATP are intense. Requests for evaluation results come frequently from individual members of Congress and their staff, from Congressional subcommittees, the General Accounting Office, the Executive Office of the President, the Office of Management and Budget, the Office of Inspector General, the Press, think tanks, industry groups, and others.

Title II of the American Technology Preeminence Act of 1991 (P.L. 102-245), enacted in 1992, directed that a comprehensive report on the results of the ATP be submitted to each House of the Congress and the President not later than 1996. This report was delivered in April 1996 (The Advanced Technology Program 1996).

In addition, the ATP, like other federal programs, is subject to the evaluation requirements of the 1993 Government Performance and Results Act (GPRA). The GPRA resulted from a bipartisan effort to improve accountability, productivity, and effectiveness of federal programs through strategic planning, goal setting, and performance assessment. The ATP/NIST is developing assessment plans and techniques, and carrying out evaluation studies in compliance with the GPRA. The ATP receives many inquires about its evaluation tools and methodologies from other agencies, as well as from similar programs in other countries.

To square the often urgent demands in the short run for evaluation results with the reality that patience is required to realize and validate empirically long-run program outcomes, the ATP has adopted a multicomponent evaluation strategy. Its main components include (1) descriptive (statistical) profiling of applicants, projects, participants, technologies, and target applications; (2) progress measures derived principally from surveys and ATP's "Business Reporting System;" (3) real-time monitoring of project developments by ATP's staff; (4) "status reports" on completed projects; (5) microeconomic and macroeconomic case studies of project impacts; (6) methodological research to improve the tools of longer term evaluation; (7) special-issues studies to inform program structure and evaluation; and (8) econometric and statistical analyses of the impacts of projects and focused programs.

Overview of ATP's Evaluation Implementation

The ATP's Economic Assessment Office has developed ATP's approach to economic evaluation in consultation with leading economists in the field. The Economic Assessment Office holds periodic workshops to obtain feedback on its approach and plans, to review work in progress, and to solicit advice on future directions. For example, workshops on ATP's evaluation, cochaired by Professor Zvi Griliches of Harvard University, were held at NIST in December 1994, September 1995, and January 1997; and at the National Bureau of Economic Research (NBER) in August 1997.

In conjunction with planning future directions of its evaluation effort, the ATP commissioned several background reports, including an early report on performance measures by Link (unpublished), a report by Jaffe on spillovers—what they are, how they arise, and how ATP can increase its effectiveness by enhancing spillover effects (Jaffe 1996), and a report by Mansfield on problems and opportunities in estimating social and private returns from ATP projects (Mansfield, 1996).

Periodically the ATP conducts economic review boards to consider proposed evaluation studies in the context of its evaluation plan. Guidelines are provided to evaluation researchers on proposing studies to the ATP (Ruegg 1996). In order to access leading academic researchers, the ATP has funded many of its recent evaluation studies through a collaborative arrangement with the NBER.

One activity in support of ATP's evaluation is the compilation and analysis of databases—mainly the ATP "Awards Database" and the ATP "Business Reporting System"—to provide answers to numerous questions about what, where, and who ATP is funding, and to measure early results. Descriptive information important to assessing the portfolio of ATP projects comes from the Awards Database. The Business Reporting System, an integrated set of databases comprised of data compiled by electronic survey of project participants, is used to track the evolution of projects towards achieving their business and economic goals. It is described further by Powell in a paper in this collection. The Business Reporting System database has considerable potential for use in evaluation research.

Surveys are another tool used by ATP's evaluation. The ATP sponsored two broad surveys of funded companies by third-party contractors using telephone interviews to assess the progress of early projects not included in its Business Reporting System (Solomon 1993 and Silber 1996). The later survey included an assessment of the satisfaction of participants with the program. Another survey, the results of which are featured in a paper in this collection, focused on research acceleration (Laidlaw 1997). In a study now underway, Hall, Link, and Scott conducted a survey to collect information on the roles universities are playing in ATP-funded projects.

The case study method is an important tool for developing an understanding of how the projects actually function and how they yield results. Two case studies of ATP projects are featured in this issue (Link 1997 and CONSAD 1997), and another case study is treated indirectly in the paper by Wang, who expounds on key methods used to evaluate the impact of medical technologies. Several other studies now underway also entail case study, including a study by Vonortas on research joint ventures, and a study by Gompers and Lerner on financing issues.

A recently completed study used a case study approach to develop preliminary estimates of the potential benefits of an inclusive portfolio grouping of ATP projects (RTI 1998). Seven individual case studies of tissue engineering projects were conducted. The study entailed development of an evaluation framework that the ATP could consider for possible adoption—with or without further modifications and extensions—for evaluating a wide variety of technologies with medical applications. This work by Research Triangle Institute has stimulated further examination of the framework in preparation for future evaluations of medical technologies.

The ATP has recently launched its first effort at focused program evaluation, targeting its Digital Video Focused Program. The first phases of the effort entail identifying potential spillover pathways, developing an evaluation model, developing a data collection plan, and establishing a baseline for comparison. Two alternative approaches proposed by different contractors are being tested simultaneously, one approach by the Center for Economic Research at the Research Triangle Institute, and one by economists at the University of Kansas. It is too early in the process to report results from these efforts.

Another activity underway is to prepare status reports for all completed ATP projects. These reports provide a "snapshot" of developments after the ATP-funded phase of the research has finished. The emphasis of these reports is on technical and commercialization progress, publications, patents, outside recognition, and the outlook for future developments. The first set of status reports covered the first 38 ATP projects completed as of March 1997, plus approximately a dozen projects that were terminated during this time without completing. The next set of status reports is underway. Even though the status reports do not alone provide a thorough assessment of project impact, they update developments while the information is still fresh and relatively easy to document, and they are expected to be an important step towards individual project assessment, and towards the ability better to characterize ATP's portfolio of projects.

Most industrialized countries have programs similar to the ATP, and these other programs offer potential insights for the ATP. Hence, one of ATP's evaluation activities has been to collect information on foreign programs. We can learn from the experience of the other programs, as well as use the information to perform "determinations of eligibility of foreign-owned U.S. subsidiaries" to participate in the ATP, a requirement of Congress.

In addition to the studies mentioned above and treated in this collection, the ATP has conducted other evaluation studies and has a number of other studies underway. Research topics include spillover identification and evaluation; research collaborations; inter- and intra-industry diffusion mechanisms, patterns, and rates; development and application of new and improved qualitative and quantitative models for measuring economic impacts of publicly funded, privately executed technological advances; impact on firm productivity of government-funded research; technology financing issues; and organizational issues affecting project structure, participants, and outcomes. Some of these studies provided the basis of presentations at an international conference, "The Economic Evaluation of Technological Change," Washington, DC, June 15–16, 1998, sponsored by the ATP in conjunction with the NBER.

Evaluation Is an Ongoing Activity

Early evaluation studies suggest that the ATP is on track, meeting its objectives, and delivering results for the U.S. economy. But at this time only rough quantitative and qualitative projections of project impacts are possible due to limited information and uncertainties about the ultimate outcomes. These measures will become better informed as commercialization and diffusion activities progress. By tracking developments as they unfold, we expect over time to be able to reduce the estimating errors, extend the scope of analysis, and provide better measures. Over the coming years, the ATP expects to contribute significantly to the body of work on technology impact assessment and to build towards a more comprehensive view of the impacts of the ATP.

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Author Biography

Rosalie T. Ruegg, Director of the Economic Assessment Office of the Advanced Technology Program (ATP), develops and leads ATP's evaluation efforts to meet GPRA and program management requirements, advises on economic and business issues, and oversees ATP's peer review process performed by non-government industry, business, and economics experts. She has designed and presented in the U.S. and abroad numerous courses on economic topics for universities and government agencies, and has more than 50 publications, including a text book. Her interests center on technology policy, the economics of technological change, and performance measurement, and she is frequently an invited speaker on these and other topics.

The Importance of "Spillovers" in the Policy Mission of the Advanced Technology Program*

Adam B. Jaffe
Brandeis University and National Bureau of Economic Research
Waltham, MA 02254

Abstract

Government policies like the Advanced Technology Program ("ATP") are intended, at least in part, to remedy the "market failure" inherent in the fact that a significant portion of the social benefits of new knowledge and technology are not captured by a firm that invests in R&D. ATP's project selection, and its evaluation of the impact of its program, can be made more effective by explicitly incorporating the analysis of such "spillovers." For project selection, this means identifying technological, organizational and economic factors that tend to point to a large "spillover gap," or deviation between the social and private rates of return to a proposed project. For program evaluation and assessment, it means adapting existing study methods that measure social returns to innovation in ways that explicitly capture spillover effects.

Economic Analysis of R&D Spillovers

Sources of Spillovers

Spillovers have been of interest to economists since at least the nineteenth century. Alfred Marshall, one of the founders of modern microeconomics, argued that R&D spillovers were on the rise, remarking, "the secrecy of business is on the whole diminishing, and the most important improvements in method seldom remain secret for long after they have passed from the experimental stage" (Marshall 1920).

Analytically, it is useful to distinguish several different mechanisms by which R&D generates spillovers. For convenience, I refer to these as "knowledge spillovers," "market spillovers," and "network spillovers." In order to think through the implications of spillovers for ATP, it is useful to consider each of these separately, and then to note that they also interact in a way that tends to increase their combined effect.

Knowledge Spillovers. The quote from Marshall refers to the phenomenon of knowledge spillovers. Knowledge created by one agent can be used by another without compensation, or with compensation less than the value of the knowledge. Knowledge spillovers are particularly likely to result from basic research, but they are also produced by applied research and technology development. This can occur in obvious ways, such as "reverse engineering" of products, and also in less obvious ways, such as when one firm's abandonment of a particular research line signals to others that the line is unproductive and hence saves them the expense of learning this themselves. The spillover beneficiary may use the new knowledge to copy or imitate the commercial products or processes of the innovator, or may use the knowledge as an input to a research process leading to other new technologies.

In some circumstances the creation of knowledge spillovers is intentional on the part of the innovator; the publication of scientific papers is, at least in part, intended to spread new knowledge so that it can be used by the widest possible audience. In the case of patented inventions, society requires disclosure of new knowledge as a quid pro quo for the granting of monopoly rights in the commercial use of an invention. The effect of this disclosure is, in principle, to make the new knowledge available to others for the purpose of facilitating new and different applications, while at the same time protecting the inventor against copying.

More generally, commercial development and use of new knowledge will tend to cause it to spread, despite any desire of the inventor to prevent such spread. Economic exploitation of new knowledge requires the sale of new products or the incorporation of new processes into commercial use. Such commercialization tends, in general, to reveal at least some aspects of the new knowledge to other economic agents. Hence the very process of economically exploiting the knowledge that research creates tends to pass that knowledge to others. Because the spread of knowledge is greatly affected by the commercial use of new

* This paper is based on a study that I performed for the ATP, Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program, NIST GCR 97-708. I have benefited from comments and useful discussions with Zvi Griliches, Jeanne Powell, Rosalie Ruegg, and Richard Spivack. Some of the ideas in this paper grew out of previous joint research with James Adams. The views expressed herein are my own, however, and should not be attributed to any of these individuals or to the ATP.

technology, even the analysis of "knowledge" spillovers must be informed by an understanding of the market mechanisms that govern the spread of new technology.

Market Spillovers. Market spillovers result when the operation of the market for a new product or process causes some of the benefits thereby created to flow to market participants other than the innovating firm. It is this "leakage" of benefits through the operation of market forces, rather than the flow of knowledge itself, that distinguishes market spillovers from knowledge spillovers. Any time a firm creates a new product, or reduces the cost of producing an existing product, the natural operation of market forces will tend to cause some of the benefits thereby created to be passed on to buyers.

Consider first the case of new or improved products. It is likely that a firm that sells a better mousetrap will charge a price that is higher than that being charged for ordinary mousetraps. But innovative products, even those that are patented or otherwise protected from direct competition, will generally be sold at prices that do not fully capture all of the superiority of the new product relative to what was available before. As a result, consumers will be made better off by the introduction of the new product. This increase in consumer welfare is a social benefit from a new product that is not captured by the innovator. Similarly, if a company does R&D to lower its production cost, it will typically lower its selling price as a result. Again, the innovator's customers are better off, and a benefit is created that is not captured by the innovator. Of course, innovation often results in both higher quality and lower prices; thereby benefiting customers even more.

Network Spillovers. Network spillovers result when the commercial or economic value of a new technology is strongly dependent on the development of a set of related technologies. An example of network spillovers exists among all of the different developers of application software for use with a new operating system platform. If one firm develops a particular application, people will buy it only if many other firms develop other sufficient applications so that the platform itself is attractive and widely used. The term "network spillover" is chosen because the different related research projects are like the different users of a network. The value of a network to any one participant is an increasing function of the number of participants; here the expected value of any one research project is an increasing function of the number of different projects undertaken.

If the commercial payoff to each of a set of related research projects is dependent on all or a significant fraction of the projects being completed successfully, then private firms might hesitate to undertake any one of the projects, for fear that the others will not be undertaken. Conversely, if any one firm decides to undertake such a project, it creates a positive externality for all the other firms, by increasing the probability that the "critical mass" will be achieved. Note that this positive externality or spillover exists even if there is no knowledge spillover among the firms (although it is likely that knowledge spillovers would also be occurring).

The existence of network externalities creates a "coordination problem" that is another possible market failure associated with research. Where network externalities are important, it is possible that firms' inability to coordinate their efforts will lead to a misdirection of research effort, away from the activities associated with network externalities, even if firms are in the aggregate undertaking a socially efficient level of research effort.

It is important to emphasize that the coordination problem only arises if there are reasons why a single firm cannot develop all of the necessary related components (or contract with others for their development) and thereby internalize the network externality. Thus while you cannot run a computer without an operating system, the need for the operating system software does not create an important coordination problem, as the hardware manufacturer can either write the operating system itself or contract for its creation. What distinguishes the operating system (which does not create a significant network externality) from the need for applications programs (which might) is the likelihood that many different applications will ultimately be necessary, and that it is unlikely that one firm would have all the capabilities to create all of these different applications, or even to know what the set of necessary applications will ultimately look like. To put it differently, synergistic market interactions among a small number of technologies is unlikely to create a coordination problem, but when the number of technologies that must be developed is large and the necessary capabilities are diverse, the coordination problem may become severe.

There are a number of different mechanisms by which the coordination problem created by network externalities can be handled. Research joint ventures, in which a number of companies combine forces, can be used to pursue the interrelated approaches whose commercial success is interdependent. By fostering the creation of such joint ventures, ATP assists this process. In addition, the formation of focused programs targeted at a set of interrelated technologies can be used to try to ensure that a critical mass will be reached. Discussion of focused programs is beyond the scope of this paper, but is discussed in Jaffe (1996).

Private and Social Returns to R&D

Pure Market Spillovers. As noted above, the effect of spillovers is to create a gap between the private rate of return to R&D (the return or profit earned by the firm undertaking the research) and the social rate of return, which includes the private return but also includes benefits to the firms' customers and to other firms. The nature of this spillover gap in the context of market and knowledge spillovers is illustrated in Figures 1, 2, and 3.

Figure 1 illustrates a "pure" market spillover. If "Firm

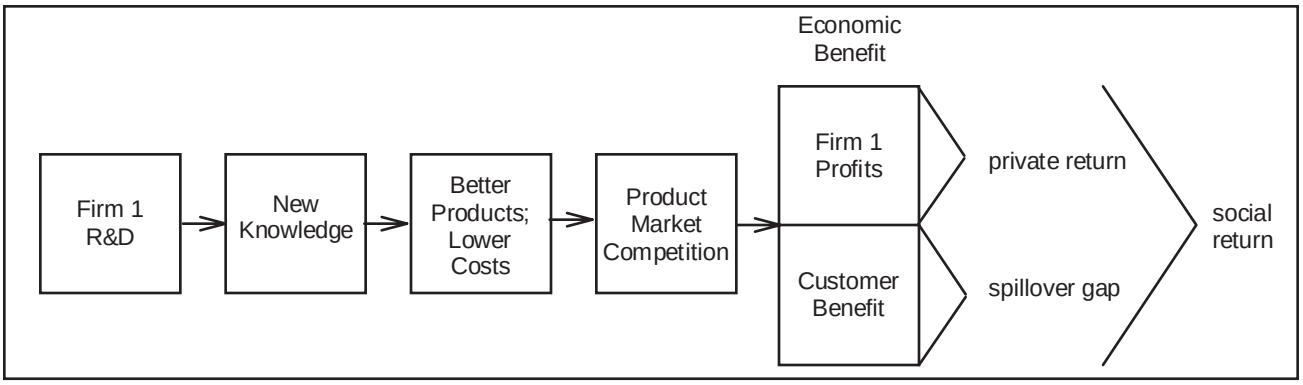

Figure 1. Private and social returns to R&D: Pure market spillover

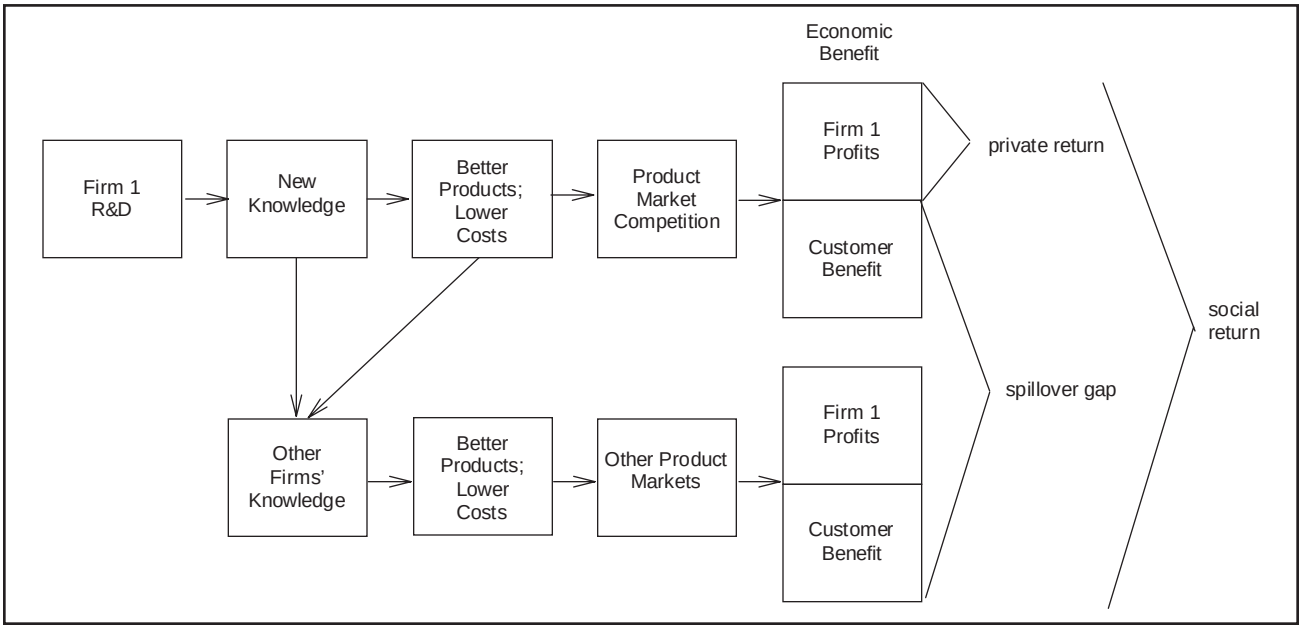

Figure 2. Private and social returns to R&D: Pure market spillover plus pure knowledge spillover

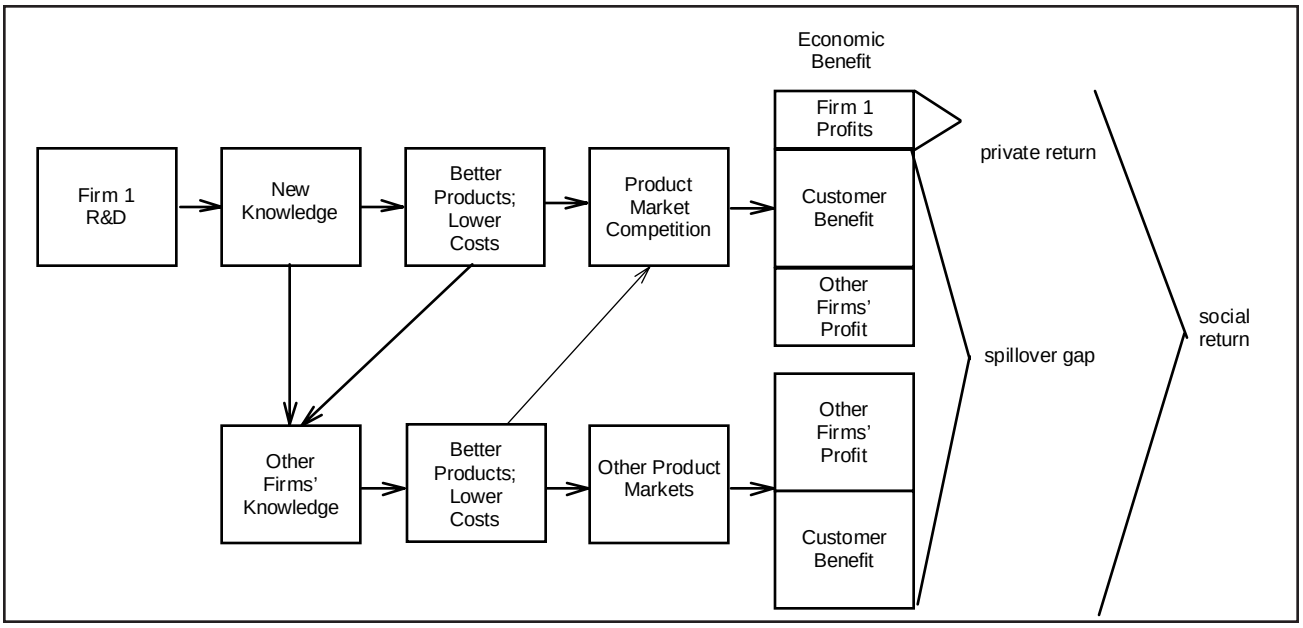

Figure 3. Private and social returns to R&D: Pure market spillover plus pure knowledge spillover plus interaction of the two

1" invests in R&D, this generates new knowledge, leading eventually to improved products or lower production costs. The operation of competition in the markets where firm 1's products are sold will divide the economic benefit of these improvements between firm 1's profits and benefits captured by customers in the form of lower costs or higher quality. In some cases, an innovating firm may not be in a position to utilize its new technology, but will need to license or sell the technology to another firm before the product or process can be implemented. In this case, imperfections in the licensing market will generally result in an additional spillover to the licensing firm.

The total social return to the innovation is comprised of the customer benefit plus the profits accruing to firm 1; the private return is only firm 1's profits, and hence there is a "spillover gap" consisting of the customer benefit. The more competitive are the markets in which firm 1's products are sold, the greater will be the share of the economic benefit that will be driven out of firm 1's profit and into the benefits captured by firm 1's customers. It is obvious from Figure 1 that the market spillovers will not be realized unless the innovation is commercialized successfully. Market spillovers accrue to the customers that use the innovative product; they will not come to pass if a technically successful effort does not lead to successful commercialization.

Note that market spillovers occur whether the purchaser of the new product is a household or another firm. In the case of improved intermediate products, then the market spillover benefits will be passed to the purchasing firms, which will in turn tend to pass at least some of this benefit to their customers. An important case of market spillovers associated with intermediate goods is where the innovation is an input to the research process, such as a new material or instrument. The purchaser is another researcher, who will typically use the new device in ways that create further spillovers.

Pure Knowledge Spillover. Figure 2 illustrates the effect of adding a "pure" knowledge spillover. By "pure," I mean a knowledge spillover that flows to firms that do not compete in firm 1's markets. Their increase in knowledge as a result of firm 1's research allows them to improve their products or lower their costs, increasing their profits and customer benefits in their markets. Both these profits and the consumer benefits are part of the social return, but are not captured by firm 1, and so the spillover gap is increased.

Note that even in the case of knowledge spillovers, the social return is created by the commercial use of a new process or product, and the profits and consumer benefits thereby created. The difference between market spillovers and knowledge spillovers is that in the former case the commercial benefits are created in the market for the new product or process that is the direct "output" of the research effort, while in the case of knowledge spillovers the commercial benefit is created indirectly through the creation of a new or improved product or process in some other market. Though as a society we value "knowledge for knowledge's sake," I am not including such non-economic value within the concept of knowledge spillovers used here.

Figure 2 indicates that the knowledge spillovers flow to some extent from firm 1's creation of new knowledge, and to some extent from firm 1's commercialization efforts. This reflects the idea that other firms may learn to some extent from papers, patents, departing employees, and other disembodied outputs of firm 1's research, but they are likely to learn more when firm 1's research results are actually embodied in new commercial products and processes. The relative importance and the speed of these two pathways will vary, depending on the nature of the research. In general, knowledge spillovers from more basic research would be expected to flow mostly from the research results themselves, and to take a fairly long time to have the commercial impact indicated in the lower part of Figure 2. On the other hand, knowledge spillovers from applied research and development are more likely to flow from the products or processes embodying the research results, and thereby have a quicker economic impact.

Thus, for the kinds of applied research and development projects that are the focus of the ATP, the realization of spillover benefits, and social returns more broadly, is strongly dependent on successful commercialization of the new technology. This is true both for market spillovers (which depend entirely on commercialization) and knowledge spillovers (which are likely to be largely dependent on commercialization). New products and processes that remain "on the shelf" do not benefit customers and hence do not create market spillovers, and their knowledge spillover impact is likely to be limited and/or distant in time. Basic research of the sort that is the mission of other federal agencies besides ATP is likely to create knowledge spillovers that are more diffuse and much more long-term.

The Interaction of Market and Knowledge Spillovers. It will often be the case that at least some of the firms that benefit from the knowledge spillover will be competitors or potential competitors of firm 1. The extreme case of this is pure imitation, where other firms copy the innovations of firm 1; more generally, firms making similar or related products may be able to improve their products or lower their costs on the basis of things they are able to learn as a result of firm 1's research. As shown in Figure 3, this complicates the picture in two ways. First, the introduction of these cheaper or better products into firm 1's markets creates some additional customer benefits, and some profits for these other firms, both of which constitute social returns not captured by firm 1. These increase the spillover gap.

At the same time that this increased competition increases social returns, it will likely reduce firm 1's profit from its own innovation. That is, the combination of knowledge spillover with competitive interaction increases the spillover gap both by raising the social return and lowering the private return. Thus "pure" knowledge

spillovers increase the social rate of return to R&D, but they do so in a way that at least does not reduce the private return. When knowledge spillovers are combined with competition, however, the effect is likely to be an actual reduction of the private rate of return. Put differently, the interaction of knowledge spillovers and market spillovers aggravates the firm's appropriability problem: not only does the firm create benefits that it cannot capture, but its own profits from marketing its innovation are competed away. Understanding this interaction has important implications for identifying which research projects are likely to have large spillovers. In the section below, I discuss the factors that economists have identified that affect firms' ability to deal with this appropriability problem.

Framework for Explicit Evaluation of Spillover Potential of ATP Proposals

The Underlying Criterion for Project Selection

It is a generally accepted criterion of public policy that expenditure programs should seek to maximize the social rate of return of the expenditures they make. Maximizing the social return on ATP's investment is complicated by the possibility that ATP funding may partially or wholly displace private R&D resources, implying that the social benefits of the research would have come about without ATP. The possibility of displacement induces a distinction between the social rate of return to the project and the social rate of return to the ATP funds. If ATP funds a project with a high social rate of return, but in so doing largely displaces private funds, then the social return to the ATP expenditure will be low despite the high social return to the project.

Third-party surveys sponsored by the ATP, statistical analyses of the ATP's database of direct reports from participating companies, and a recent study by the General Accounting Office (GAO), all show ATP grantees believe that the great majority of ATP-funded projects would not have been undertaken, or the project schedules would have been slowed and project goals delayed without ATP funding. Note, however, that even if ATP funding accelerates the project, partial displacement could still be going on. Suppose, hypothetically, that the private proponents would have spent $500,000 per year, and the budget with ATP support is $600,000 with 50/50 cost sharing. In such a case, the project would be accelerated, but $300,000 in public funds would produce only a $100,000 increase in research effort. Each public dollar would, in this example, correspond to only 33 cents of increased project funding.

The danger of displacement means that what ATP must try to do is fund projects that have a high social rate of return, and a low probability that ATP funds are displacing private funds. Of course, ATP can never know for sure the extent to which it is displacing private funds, and project proponents have an inherent incentive to understate the likely extent of displacement.

Minimizing Displacement by Maximizing the Spillover Gap

The path through this dilemma is to look for factors that cause the social and private rates of return to diverge: the presence of such factors signals the possibility that social returns may be high at the same time that the risk of displacement is low. Strong likelihood of research spillovers is just such a factor. Hence by trying to identify project proposals where the likelihood of spillovers is particularly high, ATP will fulfill its statutory mandate, and do so in a way that will yield a high social return by minimizing the extent of displacement.

The relationships among the social rate of return, the private rate of return and the danger of displacement are illustrated by Figure 4, which graphs the social and private rates of return for various hypothetical projects. Obviously, there will always be tremendous uncertainty ex ante about the private and social returns to a project. Conceptually, Figure 4 should be thought of in terms of the expected returns, i.e., the magnitude of the return if successful, times the probability of success. The public sector seeks to maximize the expected social return, and the private sector seeks to maximize the expected private return.

Since projects higher up on the diagram have higher social returns, in the absence of the displacement concern and other constraints, ATP would simply seek to find projects that are as far up as possible. From the private sector point of view, projects to the right (higher private return) are more likely to be funded, all else equal. Of course, the likelihood of private funding for any particular project will depend on its riskiness and the financial environment of the project proponents. Although it is a gross oversimplification, for the purposes of discussion I have arbitrarily divided the projects into 3 groups: "good" commercial prospects that are likely to be well-supported by the private sector, "marginal" commercial prospects that are less likely to be funded and may be funded at inadequate rates, and "poor" commercial prospects.

All projects such as "A," "B," and "C" that lie above the 45° line generate spillovers. (Their social rates of return exceed their private rates.) If ATP seeks to choose projects with the highest social rate of return, then project "C" is the most desirable of these projects, and ought to be the prime candidate for funding. If society as a whole faced an all or nothing choice among these projects, we would indeed want to choose C, since its overall social rate of return is higher. But it is likely that C will be funded by the private sector, whereas it is likely that A and B will not be, or will be underfunded. If ATP ranks projects based on the "spillover gap," then projects A and B would indeed be favored over C. Hence if we want ATP to generate high returns from projects that would not otherwise be funded, then we would be better off looking at the spillover gap than the overall social return.

Project D illustrates the extreme version of this problem. This hypothetical project generates high social and

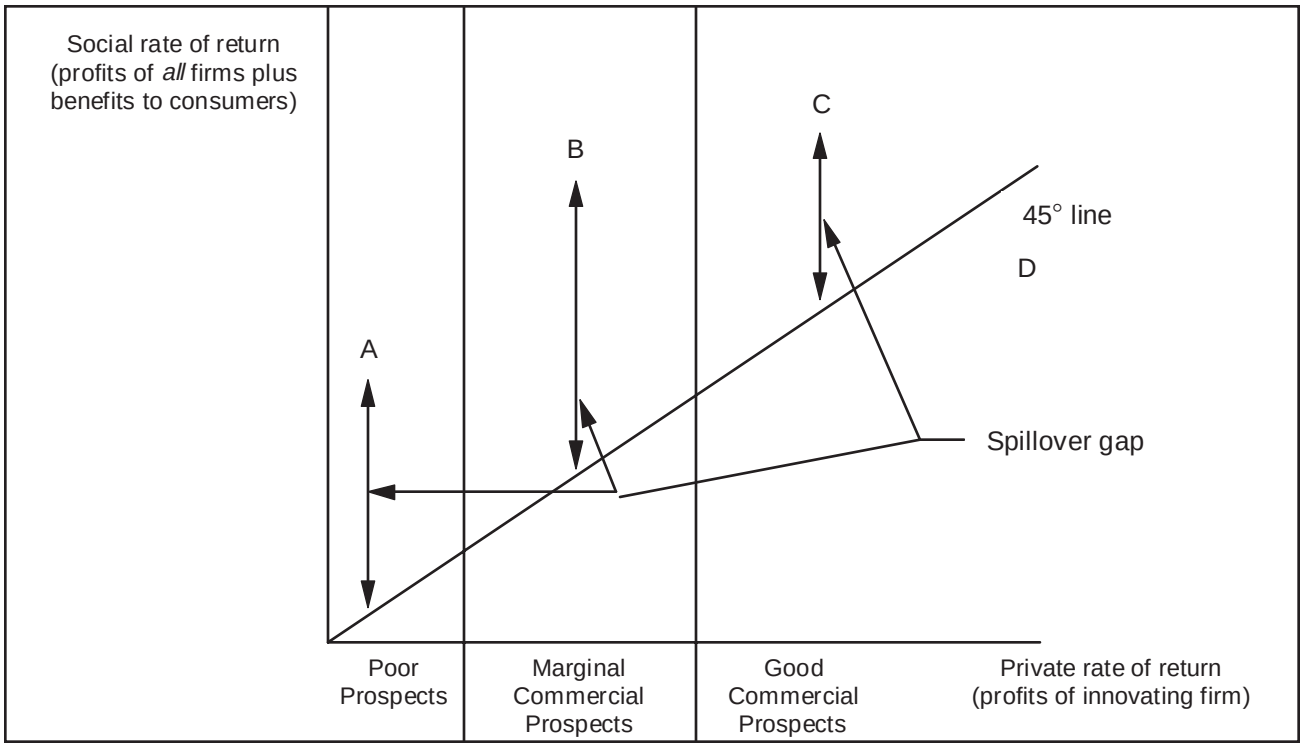

Figure 4.

private returns, but its net spillovers are negative. This might be the profile of a product that is highly successful but drives out a close substitute technology. If we were to seek to select projects only on the basis of social returns, this project would rank as highly as A, despite the fact that its private rate of return exceeds its social rate. The government has no business funding this project, however, given that its net effect on all parties, other than the firm performing it, is negative.

If ATP ranks projects based on the "spillover gap," than projects A and B are both attractive. But project A, which has large social returns but very low private returns, may not be a viable ATP project in practice. If submitted, it would score high on ATP criteria that emphasize potential spillover benefits, but the ATP would face the dilemma of a weak business case and an uncertain path to commercialization and the achievement of the potential benefits. Hence projects such as B, which have a significant spillover gap but also offer some prospect of private returns, are the most appropriate candidates for the ATP.

In reality, of course, we will have only coarse estimates of the social rate of return or the spillover gap. The fact that these prospects can only be known with great uncertainty strengthens the superiority of the spillover gap over the social rate of return as a decision criterion. Although projects like A do exist, there will, in general, be some correlation between the private and social rates of return. For example, all else equal, both rates will be higher for projects with higher success probabilities and projects whose product (if successful) serves a larger market. If we focus only on the social rate of return, then there is a danger that we will fund projects that appear to have a high social rate of return, where the only reason the private sector is not pursuing this project is because its overall prospects (affecting both the private and social returns) are being overestimated or overstated by the project proponents. If we focus on the spillover gap rather than the apparent overall social rate of return, we are less likely to step in to fund projects for which the explanation for lack of private funding is that they are not really very promising projects.

To state this point slightly differently, the ATP decision process should recognize that its information is imperfect, and that errors are going to be made. Further, information that is available about a project ought to be examined not only for what it says explicitly about social returns, but also for it what it implies about the probability of errors being made. In some cases, the "facts" being put forth to support the likelihood of large social returns for a project are facts that equally well support the likelihood of large private returns (e.g., a large market for the resulting product). If these purported facts are true, then both private and social returns from the project will be high, i.e. we will be at points like C (or even D) in Figure 4. Now, the ATP cannot know with certainty if the "facts" are really true, and cannot know why, if they are true, the private sector would not fund the project on its own. Logically, there are several possibilities: (1) the facts as presented are actually false, i.e., the market is not really large or else the probability of success is so low that the expected (social) net present value of the investment is negative; (2) the facts as presented are true, and the private sector knows it and would, indeed, fund the project with or without government help; or (3) the

facts are true, and there is some reason why the private sector will not fund the project (or will not fund it adequately or in a timely way) despite the potential payoff.

Some projects will, of course, fall into category (3), but the ATP should be worried about possibilities (1) and (2). This worry can be minimized by seeking a large spillover gap, not just a large social return. If projects with apparently high potential private returns are to be funded, there should be a careful analysis of the reasons as to why the project is not being funded despite its large potential payoff.

Measuring Rates of Return and Spillovers in Impact Studies

A possible excuse for the delay between the time Alfred Marshall talked about spillovers and the time economists made serious efforts to measure them is that they are inherently difficult to observe. As Paul Krugman has noted, "knowledge flows . . . are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes" (Krugman 1991, p. 53). As a result, empirical measurement of spillovers is necessarily somewhat indirect. Most analyses take the form of measuring the innovative effort or output of one agent or set of agents, and looking for a correlation between this measure and the innovative output of another agent or set of agents.

To make such an analysis tractable and meaningful, one must identify which agents are the likely recipients of spillovers from particular research efforts. This typically involves developing a metric for measuring the "closeness" of different agents—either in terms of technological similarity, geographic proximity, or economic relationships, such as vendors and their customers. To infer the existence of spillovers from a correlation between the research effort of one group of agents and the research output of other agents that are somehow "close," it is necessary to control for (1) the innovative effort of the second group, and (2) variations in "technological opportunity" that might be affecting the productivity of research effort for both the "spilling" and "receiving" agents, inducing a correlation between an agent's research success and the effort of other firms that need not be related to spillovers.

Studies of this sort allow the calculation of the "excess return" to R&D investment, i.e., the difference between the rate of return calculated including the effects of the investment on the recipients of spillovers, and the rate of return calculated excluding spillover effects. Depending on the nature of the study, this excess return or spillover gap may encompass knowledge spillovers, market spillovers, or both. In general, the spillover gap is found to be positive, suggesting that the negative competitive externality is generally outweighed by positive effects of knowledge and consumer surplus externalities.

Measurement of Market Spillover

The oldest line of work focuses on spillovers embodied in products and measures closeness using supplier-customer relationships. For example, Terleckyj (1974) looked at industry data, constructing a measure of "borrowed" R&D for each industry on the basis of the R&D of the industries from which it purchased intermediate inputs, including capital equipment. He found that the productivity effects of R&D in downstream industries implied an excess return to industry R&D of 20% to 50% (compared to a private rate of return of about 30%). This measure of market spillovers may also contain an element of knowledge externalities, to the extent that the downstream firms are engaged in their own research and benefit indirectly from the research of their suppliers.

Scherer (1982 and 1984) took another cut at this problem. By examining patent data, he estimated the fraction of inventions originating in each industry that would be used by each industry. This allows the creation of a "technology flow" matrix which can be used to allocate industrial research by the industry in which it will be "used" regardless of the industry in which it is performed. He shows that this "used" R&D variable is more strongly correlated with industry productivity growth than is a variable measuring R&D performed in the industry.

Mansfield, et al. (1977) used a case study approach instead of looking at aggregate industry R&D statistics. They identified 17 specific innovations, and attempted to estimate the actual cost and overall social benefits of each. In particular, they took great care to analyze the impact of the innovations on customers, and also on competitors. They did not, however, specifically seek to identify knowledge externalities. For this group of innovations, the median private rate of return was about 25% and the median social rate of return was about 50%.

Bresnahan (1986) and Trajtenberg (1990) have quantified the consumer surplus spillover from mainframe computers in the 1960s and the CT scanner in the 1970s. Bresnahan calculates that between 1958 and 1972 financial service firms paid $68 million for computing services, but received benefits equal to $200 to $400 million. Although he does not explicitly calculate rates of return, this clearly shows that the social rate was several times the private rate. Trajtenberg calculates that the social rate of return to improvements in CT scanners averaged between 180 and 350 percent per year, depending on how foreign R&D investments are treated. While Trajtenberg also does not calculate private rates of return, approximately half of the producers, including EMI, the original innovator, eventually left the business, apparently because of mounting losses.

Measurement of Knowledge Spillovers

In my 1986 paper, I used patent data for about 500 manufacturing firms to characterize the "technological

proximity" of all pairs of firms on the basis of the extent of overlap of technological classification of their patents. I then constructed a measure of the "spillover pool" for each firm, as the sum of all other firms' R&D, weighted by their proximity to the receiving firm. I found that the pool variable had positive effects on firms' patents, profits and market value, all controlling for the firm's own R&D. For patents—a purely technological measure of research output—roughly half of the aggregate impact of R&D was in the form of spillovers, or, conversely, the social productivity of research was roughly twice as great as the private productivity. For economic measures of research output such as profits, productivity and market value, I found that the spillover effect was roughly half as large as the private return.

Interestingly, the effect of the pool was found to be itself a function of firms' own R&D. The more R&D a firm does itself, the more it benefits from spillovers from others. With respect to profits and market value, firms that have significantly less than the mean R&D level actually suffer a negative effect from the spillover pool. This is interpreted as saying that both knowledge and competitive externalities are present, with the former outweighing the latter on average, but the latter outweighing the former for firms that do little R&D themselves.

Summary of Estimates of Spillover Magnitudes

Griliches (1992, Table 1) summarizes the results of many of these studies. He concludes "R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates." While all of this work carries econometric limitations and presents only indirect evidence that spillovers exist, the weight of the evidence does seem to be increasingly convincing that spillovers create a large gap between the private and social rate of return. There are two ways to look at this gap. In absolute terms, it appears that the excess of the social rate of return over the private rate—the rate of spillover—is something like 15 to 30 percent, with some estimates much higher than that. Another way to look at this is relative to the private rate of return. Again, estimates vary somewhat, but spillovers seem to create a gap between the private and social return that is equal to 50 to 100% of the private rate of return. Note that the individual studies underlying these ranges tend to emphasize either knowledge externalities or market externalities. I can think of no study that, at a conceptual level, is designed to capture both, although relationships between the two in the data make it likely that each kind of study picks up some of the other effect. Hence it is likely that these estimates have some tendency to underestimate the combined effects.

Conclusion

In order to be effective in achieving its statutory objectives, ATP must try to determine which projects proposed to it will generate large spillovers, and which will not. Economists and other social scientists have identified certain aspects of a project's technological and market environment that tend to be associated with large or small spillovers. By incorporating the explicit analysis of such factors into both project choice and evaluation of project impact, ATP can make better decisions

This is an inherently difficult and uncertain task, and it is one that requires an unusual combination of technical, business and economic analysis. Perfect prediction cannot be achieved, any more than it can be achieved for the purely technical success of research. We know enough about spillover prediction and measurement to improve ATP's project selection and evaluation of outcomes using more systematic, explicit treatment of spillover effects. Further research can improve and extend our knowledge of spillover phenomena and how to measure them, in order to provide a firmer foundation for a program with the mission, goals, and strategies of the ATP.

The empirical evidence suggests that the average research project generates spillovers. If ATP can succeed in targeting projects with better-than-average spillover potential, then it will generate large social returns that would not otherwise have been achieved.

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Author Biography

Adam Jaffe is a Professor of Economics at Brandeis University. His research interests include the effect of incentives and regulations on the diffusion of technologies, and the role of R&D and innovation in economic growth. Jaffe coordinates the National Bureau of Economic Research project on U.S. productivity and industrial technologies.

Pathways to National Economic Benefits from ATP-Funded Technologies

Jeanne W. Powell
Advanced Technology Program, National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Gaithersburg, MD 20899

Abstract

An important component of the Advanced Technology Program's (ATP) economic evaluation plan for tracking project progress and outcomes is the administration of an electronic survey on a regular basis to participants in all projects funded since 1993. Progress of projects is compared against business plans and projected economic benefit goals outlined in their proposals. The resulting Business Reporting System (BRS) database is used for ATP project management and for evaluation research. Based on BRS data compiled through December 31, 1996, filed by 480 companies in 210 projects, funded in 19 competitions, this paper provides an overview of pathways to achieving targeted commercial and broader economic goals. Progress reports for the group of projects provide a variety of evidence of (a) opportunities for economic spillovers and national economic benefit and (b) activities supporting technology diffusion.

The ATP's Business Reporting System: A Tool for Economic Evaluation

The use of comprehensive surveys of ATP projects and participants has been a central component of ATP program evaluation from the beginning. In the early years of the program, the ATP relied on third-party surveys of projects to determine their progress. In early 1994, the ATP implemented the Business Reporting System (BRS), a comprehensive data collection tool for tracking, on a routine and regular basis, progress of projects against business plans and projected economic benefits outlined in the project proposals and updated over the course of the projects. The survey system, electronically administered, has been implemented for projects selected in 1993 and since, from their inception. To ensure maximum confidentiality of information and detail concerning the multiple commercialization activities of joint venture members, data is collected at the individual participant level (directly from individual companies, universities, and not-for-profit organizations) within a project.

The survey information collected through the BRS comprises part of the integrated ATP database framework. It is used for ATP project management, as well as for performing evaluation research. Over time, the data is expected to support comprehensive analyses of the behavior of firms conducting R&D and developing new technologies, of their business progress, and of resulting economic benefits.

The Business Reporting System consists of five major parts:

- *A Baseline Report*. At the beginning of the project, in the Baseline Report, companies identify areas of anticipated applications of the technology being developed with ATP funding. They identify quantitative business goals, including cost and/or performance targets; key attributes of the technology needed to achieve these goals; planned strategies for commercialization; e.g., in-house production, licensing, and strategic alliances. They outline their strategies for protecting intellectual property; and identify their plans for disseminating non-proprietary information.
- *Anniversary Reports*. Annually, in the Anniversary Report, companies expand upon the baseline information to identify new applications of the technology and to cover progress towards implementing commercialization strategies. They report on new intellectual property created, early business developments, collaboration experiences, attraction of new funding, new intellectual property created, and dissemination of information through conferences, publications, and other mechanisms. They also provide a summary of company financial data.
- *Closeout Report*. At the project conclusion, in the Closeout Report, companies update Anniversary Report information and identify remaining technical and business barriers to commercialization of the technology, define specific business goals for the following five-year period, and indicate expected future effects of the ATP project outside that organization.
- *Post-project Reports*. Following the end of ATP funding, companies report three times—once every two years—concerning actual progress in commercializing the technology and impacts inside and outside the organization attributable to the technology.

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- *Quarterly Reports*. At the end of each quarter, other than the initial and anniversary quarters, companies report the most significant business developments (if any) related to the ATP projects.

Companies funded in FY 1993 and later are required to submit these reports under the terms and conditions of their ATP awards. Under ATP's agreements with project participants, all information reported through the BRS is considered proprietary and confidential. Information is released and published only in aggregate, summary statistical form. Any quoted material is presented without attribution. Nothing is released on an individual company or project basis unless the company explicitly agrees to the disclosure or the same information is publicly available such as through company press releases or Internet sites.

The BRS supports three objectives: (a) to track business progress against company plans for achieving commercialization and broad-based economic impacts; (b) to develop short-term statistical indicators of results; and (c) to build a database to support long-term evaluation of ATP's economic impact.

This paper provides a snapshot of pathways to achieving impact of projects funded in competitions held from 1993 through 1995. It draws on the BRS to capture plans for commercialization and diffusion of ATP-funded technologies resulting from 210 projects as reported by 480 separate organizations funded during FY 1993–1995. The information is based on business reports filed through December 31, 1996. The 210 projects are a subset of 352 projects funded by the ATP from 1990 through 1997. Not included are 72 projects funded in FY 1996 and 1997 because they had not yet begun reporting at the time the data were analyzed, the 60 projects funded between 1990 and 1992 because they were funded prior to implementation of the BRS, and nine projects that would have been in the BRS but were cancelled.

Data Show Opportunities for Economic Benefits

Of the subset of 480 organizations in 210 projects, 375 companies in 208 projects have reported plans for commercializing one or more applications of the ATP-funded technologies. Not surprisingly, most universities, non-profits, and government laboratories have not provided plans for commercialization, but they have reported plans for dissemination of non-proprietary information concerning technology developed with ATP funds. These plans of businesses for commercialization and of non-profits for knowledge dissemination are important because they point out two different kinds of pathways by which the technologies will have future economic impact: (1) directly through products and processes introduced in the marketplace by the innovators, and (2) indirectly through the knowledge created by the innovator and disseminated to others.

Development of Enabling Technologies

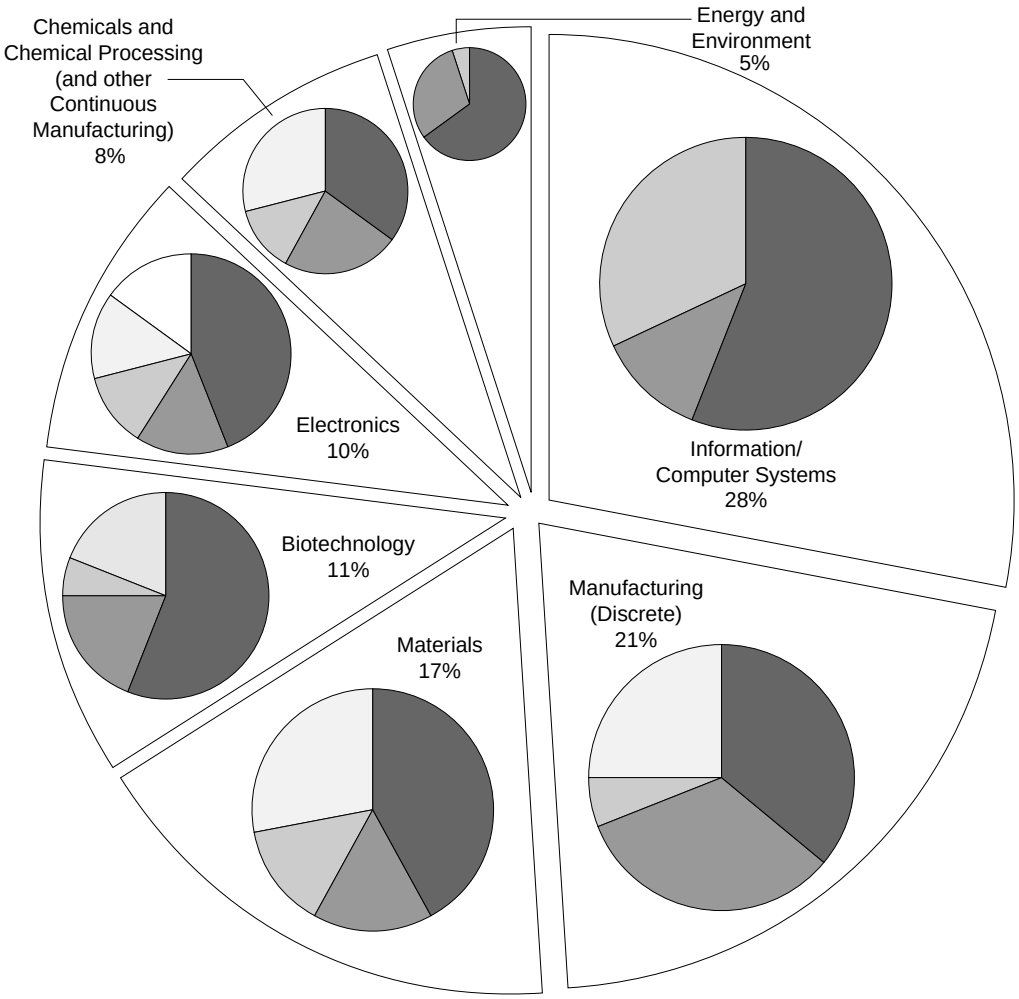
The ATP funds technology development projects, on a cost-sharing basis with industry, through both General Competitions, open to all technology areas, and Focused Competitions, targeted to specified technologies and specified goals. Many projects and entire Focused Programs, consisting of sets of related projects, involve an interdisciplinary mix of science and technology fields. The ATP uses its own 5-digit, hierarchical technology classification system to identify technology areas under development by different organizations and projects. Individual companies self select primary and secondary codes which best describe their areas of R&D.

Figure 1 summarizes the technologies according to their first and second level code assignments. More than one-fourth of the technology development projects directly involve Information Technology/Computer Systems, either hardware or software. Discrete manufacturing and materials comprise major parts of the remainder. These three areas of concentration reflect the fact that seven of the 12 ATP Focused Program areas funded in FY 1993–1995 involve substantial information technology and/or materials processing and manufacturing technology. (This distribution differs somewhat from other technology classifications published by the ATP because the distribution shown in Figure 1 (a) reflects only the projects funded in FY 1993–1995; (b) reflects R&D activity at the organization level for joint ventures, whereas, other ATP classifications are at the project level (i.e., organizations in a given joint venture project do not necessarily work in the same technology area); and (c) is based purely on the number of organizations working in a given technology area, not on the relative amount of funding to the technology area.)

Further analysis of projects funded in these broad technology areas begins to capture the interdisciplinary nature of the work. For example, the second-tier analysis in Figure 1 shows that six percent of the work in Manufacturing (Discrete) involves "intelligent" manufacturing; 12 percent of the work in Information/Computer Systems is hardware. A third-tier analysis (not presented) would show that computer hardware has a strong electronics component. Digital data storage is one example. This next level of analysis also would reveal the overlapping of projects across disciplines and the difficulty of classifying them. For instance, some computer systems components and related manufacturing technologies are assigned to the Electronics category; e.g., Displays and Semiconductors and Microelectronic Fabrication technology.

Identification of Business Opportunities

Nearly 400 project participants have identified more than 1,000 applications of the technologies under development and provided commercialization plans for nearly 800



Source: Business Progress Reports from 404 organizations in 208 projects funded 1993-1995

LEGEND for Breakdown of Technology Areas

Information/Computer Systems

- Computer Software, **56%**
- Computer Hardware, **12%**
- Other/Not Specified, **32%**

Manufacturing (Discrete)

- Automobile Manufacturing, **36%**
- Machine Tools, **33%**
- Intelligent Manufacturing, **6%**
- Other/Not Specified, **25%**

Materials

- Composites, **42%**
- Coatings, **16%**
- Metals and Alloys, **14%**
- Other/Not Specified, **28%**

Biotechnology

- Human Diagnostic Biotechnology, **56%**
- Human Therapeutics, **19%**
- Biomolecular and Biomimetic Materials, **6%**
- Other/Not Specified, **19%**

Electronics

- Displays, **44%**
- Electronic Instrumentation/Sensors and Control Systems, **15%**
- Optics and Photonics, **12%**
- Semiconductors and Microelectronic Fabrication Technology, **14%**
- Other/Not Specified, **15%**

Energy and Environment

- Energy Distribution/ Conservation, **65%**
- Energy Resources/ Generation, **30%**
- Other/Not specified, **5%**

Chemicals and Chemical Processing (and other Continuous Manufacturing)

- Catalysis/Biocatalysis, **35%**
- Separation Technology, **23%**
- Process Control, **13%**
- Other/Not Specified, **29%**

Figure 1. Technologies under development

applications spanning the spectrum of SIC industries. Figure 2 illustrates the diverse application areas of the enabling technologies funded in the Materials area. A detailed examination of individual reports reveals more explicitly the diverse linkages. For example, company reports for one project involving metal and alloy technology reveal planned applications in electrical power generation (SIC 49), chemical processing (SIC 28), and pulp and paper machinery and bearings (SIC 35). A single-company project involving coatings reports applications in seals (SIC 30), industrial machinery for printing rolls, pump components, bearings, and power transmission and computer displays (SIC 35), and sensors (SIC 38).

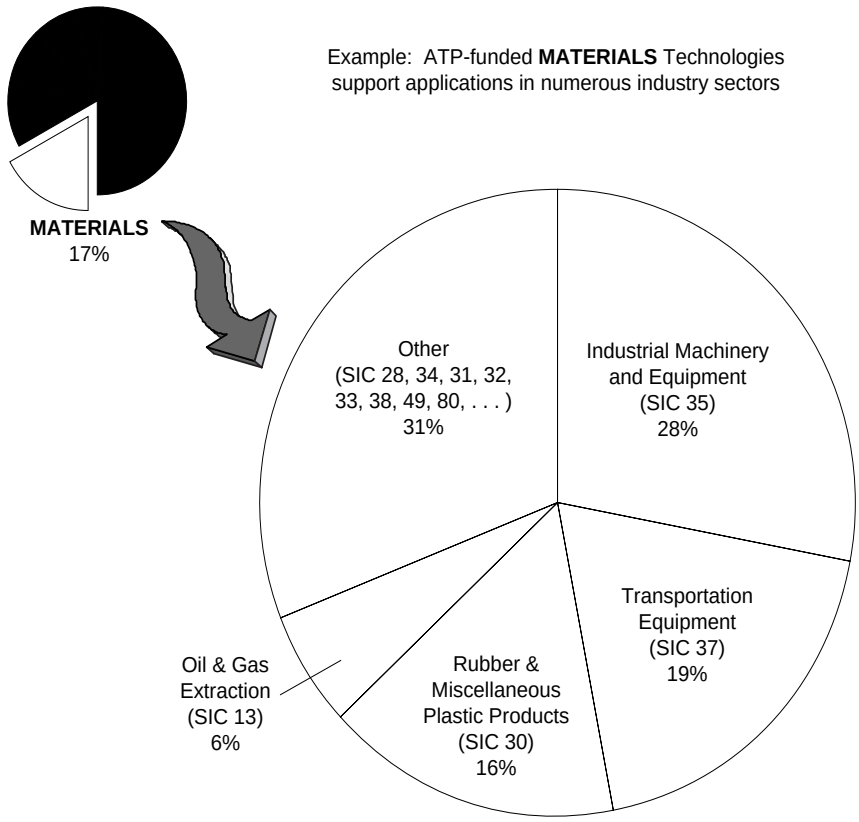
Commercialization occurs through eventual embodiment of the ATP-funded technology in a product, service, manufacturing process, or in some combination of these. Figure 3 summarizes the percentages that are expected to occur in each form. This figure suggests that most commercial deployment of ATP technologies will occur through manufactured products, with the focus on new, as compared with improved, products, processes or services. Responses to a follow-up question further indicate that for 35 percent of the applications, companies envision their application to be a "new-to-the world" solution to a market need or problem. Such applications represent opportunities to create totally new markets.

As shown in Figure 4, many companies envision that products and processes embodying the ATP-funded technology will be used in multiple stages of production extending from Raw Materials Production to End User. Sixty-three percent of the technology applications involve relatively early-stage Components Manufacturing.

The entry of the ATP technology into an early stage of the production cycle, in combination with the diversity of applications expected to result from individual projects and technologies, increases the opportunity for downstream customers/users to experience market spillovers (consumer surplus). This is, of course, especially true where an ATP-funded technology has significant cost or performance advantages over existing/defender technologies.

Business Goals

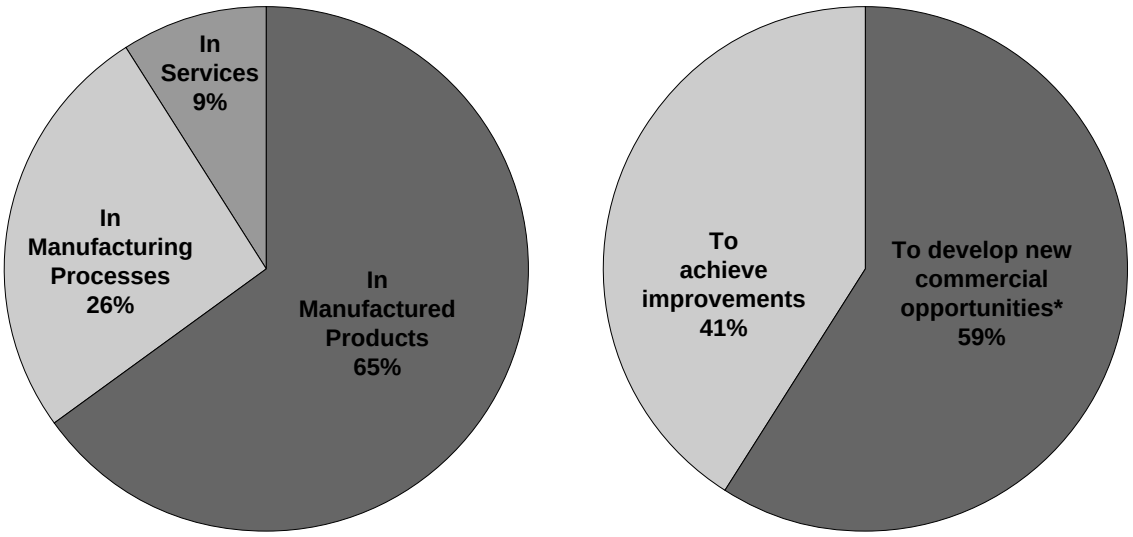
In the Baseline Reports, companies are asked to categorize, define, and quantify their business goals for the ATP-funded R&D projects. As shown in Figure 5, performance improvements appear to be a somewhat more commonly expected and significant goal than cost reduction.



Note: "Other" SIC catagories are defined in Appendix G.

Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

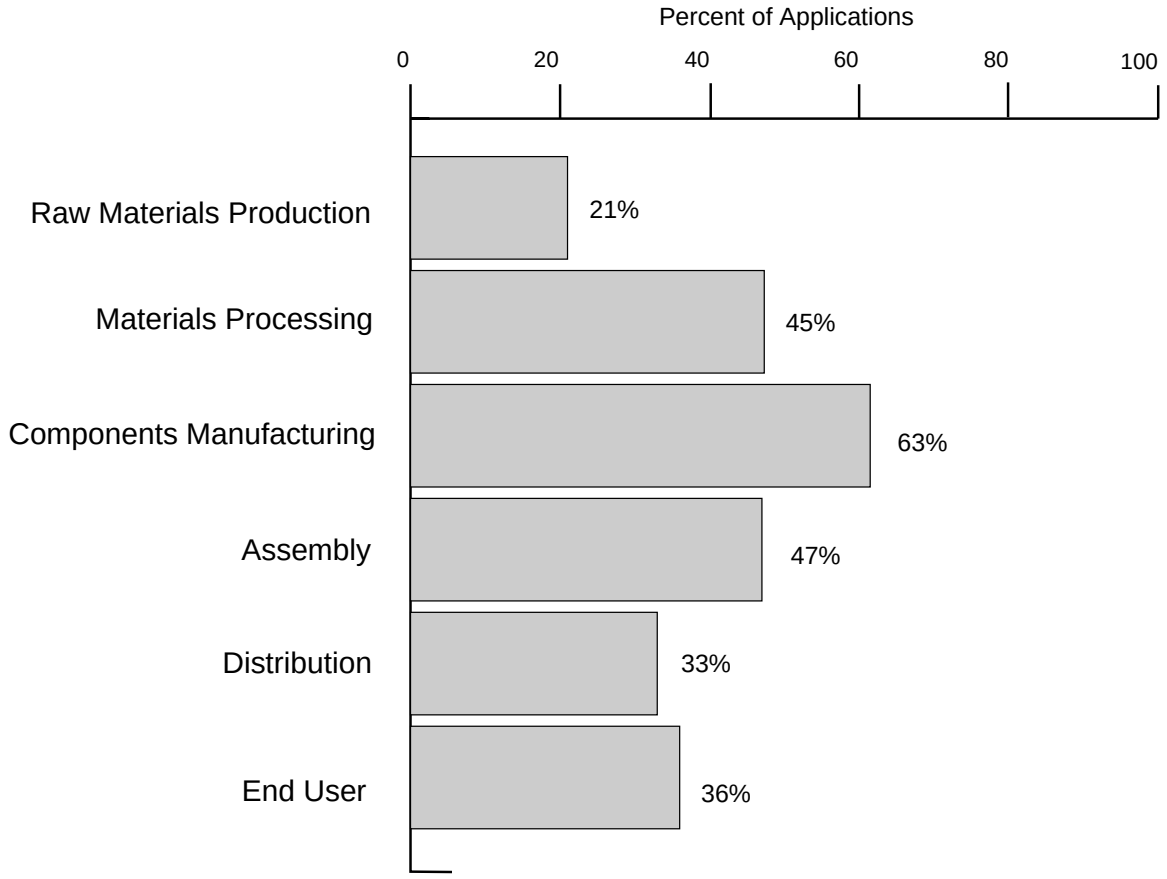
Figure 2. Plans for diverse applications of ATP-funded technologies



Note: *In response to a follow-up question (not depicted), project participants indicated that 35% of applications represent "New-to-the-world" solutions to a market need or problem.

Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

Figure 3. Types of commercialization expected



Note: Most companies plan to address more than one stage of production; many plan to address more than two.

Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

Figure 4. Stages of production in which the ATP-funded technologies are expected to be used

For 29 percent of applications, a performance improvement in the range of 100–500 percent or more is anticipated. For 28 percent of applications, a cost reduction of 25 percent or more is expected. Improvements of these magnitudes, particularly when combined with the emphasis on "new" products or lines of business, are consistent with definitions of "discontinuous" or "breakthrough" innovations used in the joint Rensselaer Radical Innovation Research—Industrial Research Institute Project funded by the Sloan Foundation (Leifer 1997). (Of course, for some projects, even a small per unit cost reduction or performance improvement can represent a significant achievement and important competitive advantage when measured across a large production volume.) Other data show that one-third of applications are expected to involve some combination of cost reduction and performance improvement over existing technologies.

Table 1 illustrates with a list of quantitative examples how ATP funding is expected to affect the technological capabilities of companies as measured by expected changes in the attribute identified as most critical to commercialization for a specific application. Quantification of cost and performance advantages of the ATP-funded technology, such as provided by this business goals analysis, is useful in tracking project progress as well as assessing business opportunities and estimating the potential magnitude of economic spillovers. Both "with" and "without ATP" goals are needed to assess the potential for ATP funding to make a difference relative to what would have occurred without government funding. An *ex ante* comparison of baseline values with project goals for key technology parameters/attributes helps to identify the anticipated degree of technological advancement and to assess the expected impact of the project. An *ex post* comparison of progress made against cost/performance targets will make it possible to assess the level of actual technical accomplishments within a business and economic context.

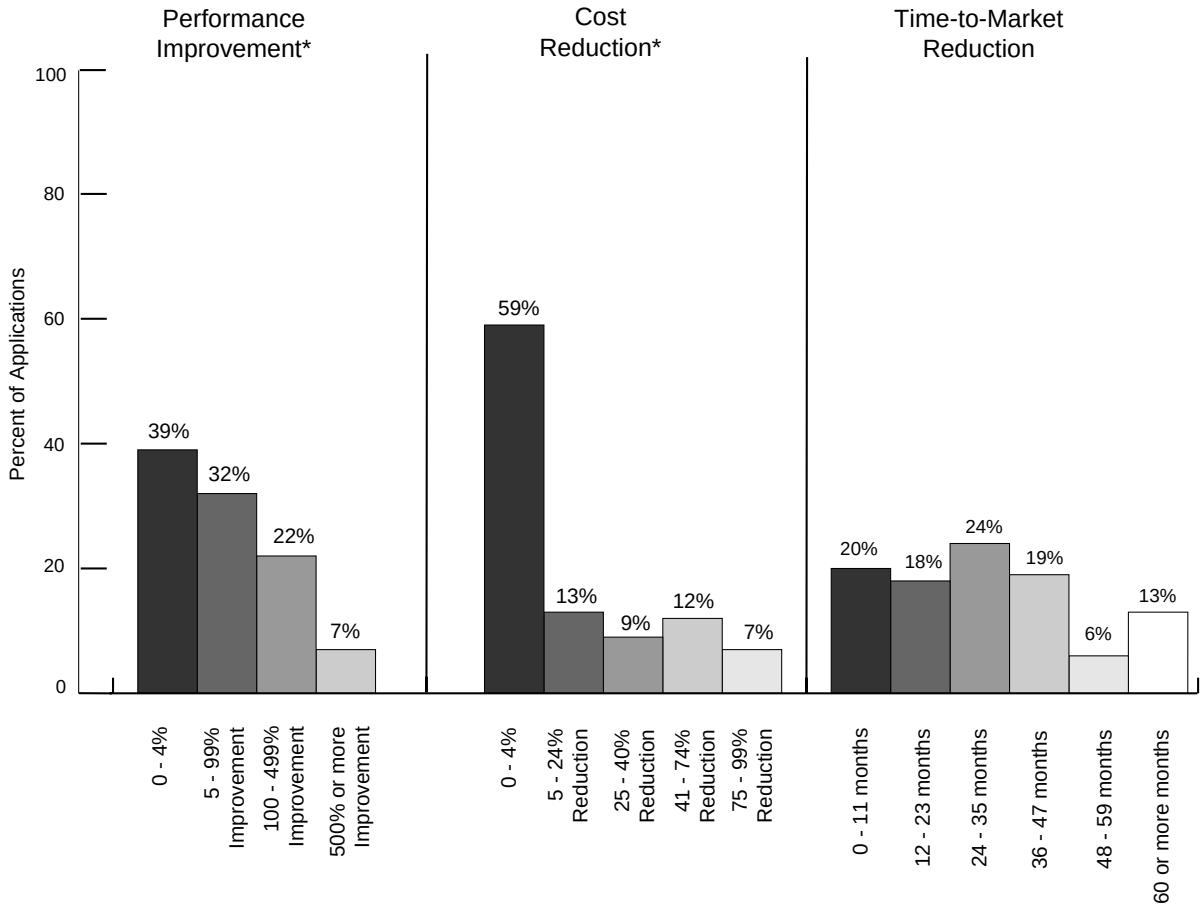
Acceleration of R&D is another commonly cited business goal of ATP projects. As shown in Figure 5, nearly all the companies expect some reduction in the time it will take to complete the R&D phase and bring their products to market/or implement new production processes as a result of ATP funding. A reduction of at least two years is anticipated for 62 percent of applications; with a reduction of four or more years expected for 19 percent of applications and a reduction of two to nearly four years expected for 43 percent of applications.

The importance of the acceleration aspect of ATP

Table 1. Examples of effect of ATP funding on company goals for the technology

Baseline	Goal with ATP Funding	Goal without ATP Funding
1 kw/$10,000	10 kw/$10,000	3 kw/$10,000
60 microseconds process speed	10 microseconds process speed	60 microseconds process speed
$100 cost	$25 cost	$100 cost
3,300 hours lifetime	10,000 hours lifetime	5,000 hours lifetime
2,500 cars/day	2,875 cars/day	2,500 cars/day
34 trains/day	51 trains/day	34 trains/day
1,000 CPU time	10 CPU time	100 CPU time
60 degrees C	100 degrees C	60 degrees C
800 nm	200 nm	800 nm
$60,000 per unit	$1,000 per unit	$10,000 per unit
1 test/day	5 tests/day	1 test/day
40 bases/minute	2,000 bases/minute	533 bases/minute
$500/medical test	$50/medical test	$500/medical test
1 gene/day sequencing	100 genes/day sequencing	5 genes/day sequencing
3.9 gigabytes data storage	60 gigabytes data storage	4.7 gigabytes data storage
$62/gigabyte	$1/gigabyte	$25/gigabyte

Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.



Note: *In a response to a different question, project participants indicate that one-third of applications involve some combination of cost reduction and performance improvement over existing products, processes, and services.

Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

Figure 5. Quantitative business goals

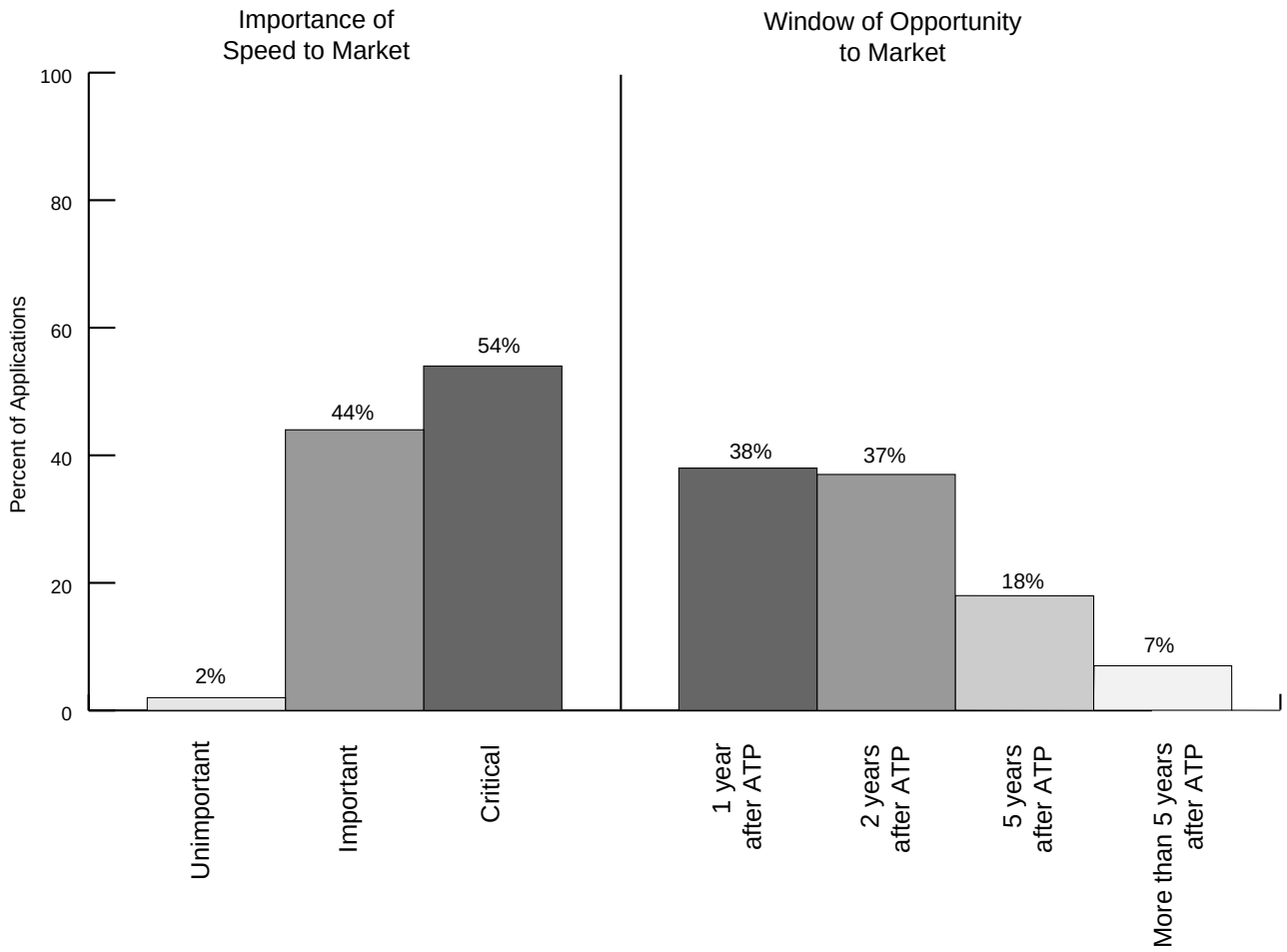
funding is reflected in Figure 6. For 98 percent of applications, speed-to-market is considered "important" or "critical;" it is considered "critical" for more than half the applications. Further emphasizing the importance of acceleration, the window of opportunity for 75 percent of the applications to enter the marketplace is considered to be within two years after ATP funding ends; i.e., it appears that companies believe they would miss the opportunity, or a significant part of it, without the acceleration enabled by ATP funding.

The following are some additional business goals cited in company business reports:

"Achieve broad adoption . . ."
"Be #1 supplier of . . . technology"
"Expand applications into . . . industry"
"Obtain a licensee by end of ATP"
"Become global expert in . . . technology"
"Diffuse technology to cover 5 technology niches"
"Increase market share by . . ."
"Be recognized as leading vendor of . . ."

Identification of Commercialization Strategies

As their primary means of commercialization, most ATP-funded companies plan to achieve commercialization for at least one application through production of a product or service in-house, in their own existing or planned facilities. As shown in Figure 7, in-house production is the focus for 65 percent of applications. For 24 percent of applications, licensing to others is the primary strategy; for 43 percent of applications, licensing is the primary or secondary means of commercialization. For 79 percent of applications, including some of those where in-house production is the primary means, licensing to others is a possible supplementary means, if not the primary focus. Thus companies recognize the opportunity to increase their revenues beyond what their internal production facilities can support. At the same time their actions increase opportunities for diffusion of the technology to other firms and potentially other applications and industries. Jaffe (1996) confirms that the potential for licensing the technology to others is a factor that makes economic spillovers relatively



Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

Figure 6. Importance of market timing

more likely.

Close supplier-customer linkages are important to successful technological innovation. Among the work that addresses this issue, von Hippel (1994) suggests that such linkages can increase the productivity of the innovation through more efficient communication of technological and market information. Given the large number of small companies involved in the projects, and the rather early stages of production they address, one would expect a large number to pursue strategic alliances for commercialization. From Figure 8 one might think the companies are not relying heavily on strategic alliances with customers, suppliers, partners in joint production, or distributors for commercialization. But further analysis at the company level reveals that (a) 91 percent of companies plan at least one of these types of alliances and (b) at least one of these types of alliances is planned in pursuing 88 percent of applications (graph not presented). As one might anticipate, the subset of reports from small businesses reveals that strategic alliances to pursue commercialization are more important for small businesses than for larger ones. Small businesses plan alliances with customers as a primary strategy for 31 percent of applications and as a primary or secondary strategy for 54 percent of applications (compared with 25 and 41 percent respectively for all respondents); small businesses plan alliances for joint production as a primary strategy for 21 percent of applications and as a primary or secondary strategy for 47 percent of applications (compared with 17 and 32 percent respectively for all respondents); small businesses plan alliances with distributors as a primary strategy for 22 percent of applications and as a primary or secondary strategy for 38 percent of applications (compared with 15 percent and 27 percent respectively for all respondents).

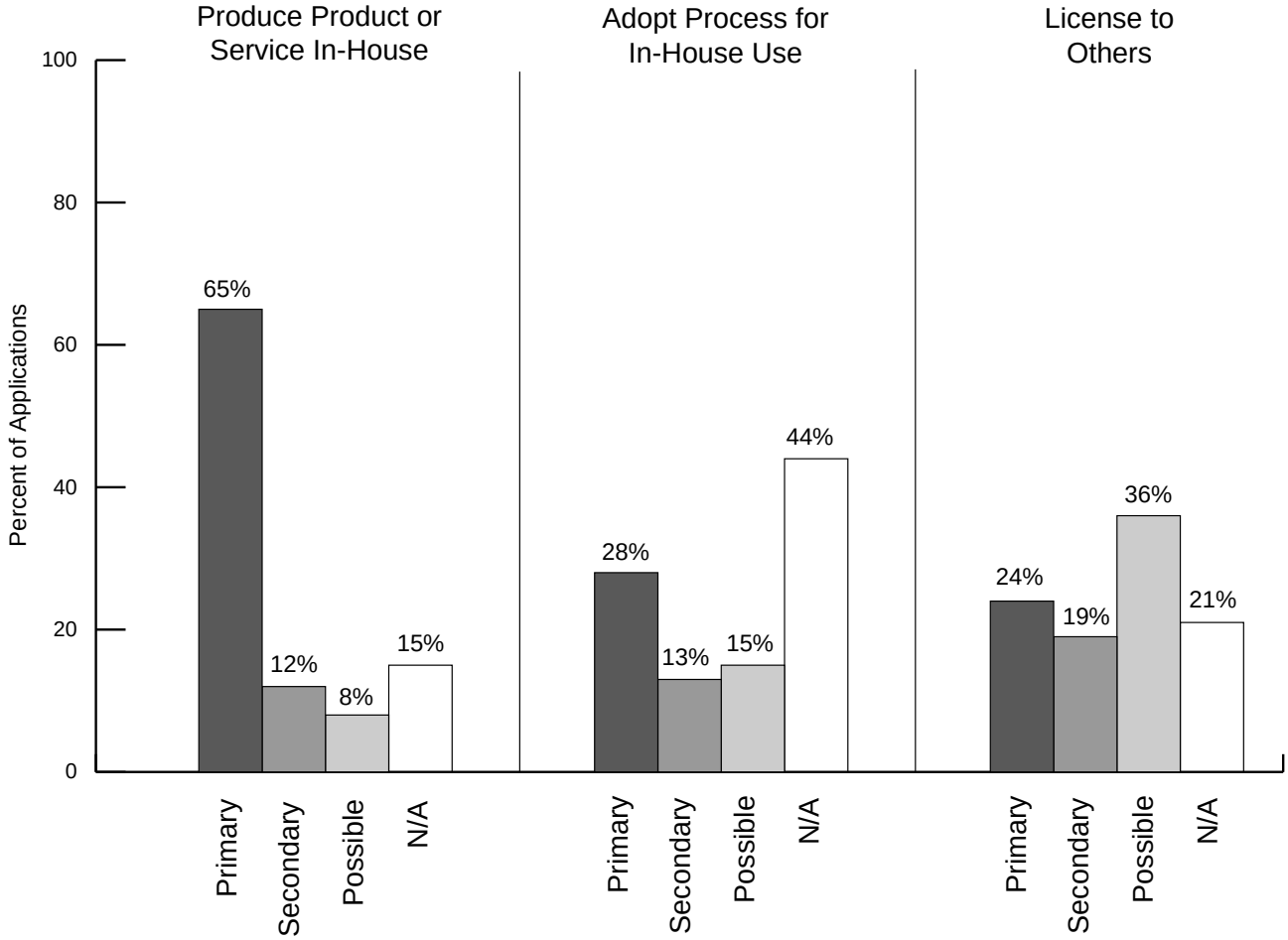
Protection and Disclosure of Intellectual Property

Protection of intellectual property through formal patent and copyright mechanisms provides legal protection against use of an invention without permission or compensation. The patent or copyright thus converts the intellectual property into a potential income-earning asset, and, for many applications and industries, is critical to the ability of

the innovator to commercialize a new technology. In return for patent protection, however, the innovator must agree to public disclosure of the patented invention and (to a lesser extent) copyrighted material. Disclosure provides a means of attracting commercial partners interested in licensing or joint production opportunities, and thus reinforces the private commercial purposes of the intellectual property protection; however, it also is a mechanism for unintended knowledge spillovers—to competitors or others who may be in a position to exploit the knowledge without paying for it. (See Jaffe 1996.)

Both aspects of patent and copyright protection are important to achieving maximum commercialization, diffusion, and social benefit of the ATP-funded technologies: Patent and copyright protection afford ATP-funded firms the necessary incentives to undertake costs of product development and marketing needed to launch a commercial product, and may help open new licensing and other partnering opportunities. The wider the commercial use of the technology and the greater the spread of information concerning resulting products and processes, the greater the opportunity for market spillovers to users and customers and for knowledge spillovers to others in a position to make use of the knowledge for their purposes.

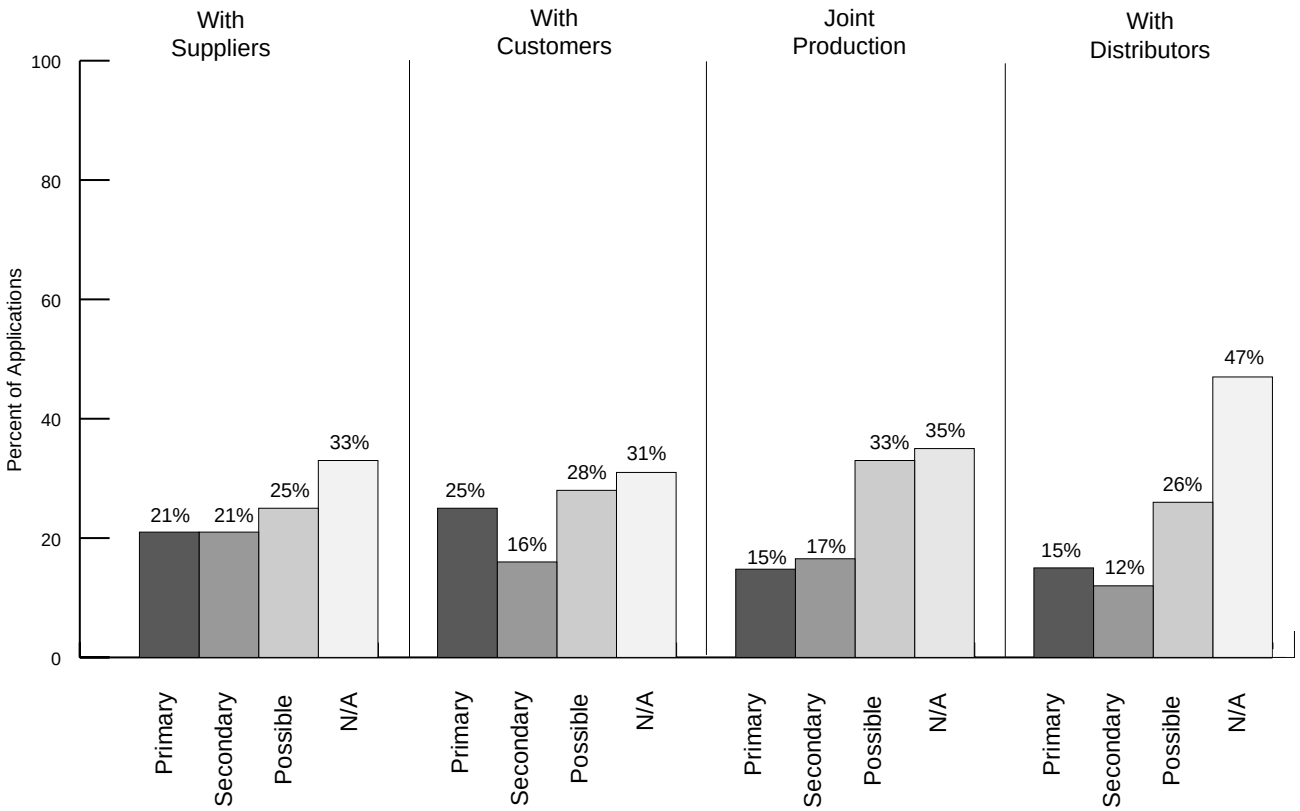
Most companies report plans to protect intellectual property created in their ATP project, whether they plan to produce in-house or to license the technology to others. As shown in Figure 9, patent protection, copyright protection, and maintenance of trade secrets are listed respectively as primary strategies by 61 percent, 27 percent, and 51 percent of companies. A more detailed analysis (not shown) indicates that ten percent of the companies listed all three strategies as primary; 15 percent listed both patents and copyrights as primary; and 25 percent listed both patents and trade secrets as primary strategies. Thus some combination of legal protection and secrecy/first mover advantages appears to be a common strategy. Of course, to the extent that companies patent their technology they cannot expect to maintain secret the same knowledge; but companies may identify some aspects of their technology best



Note: Some companies reported more than one strategy as "Primary."

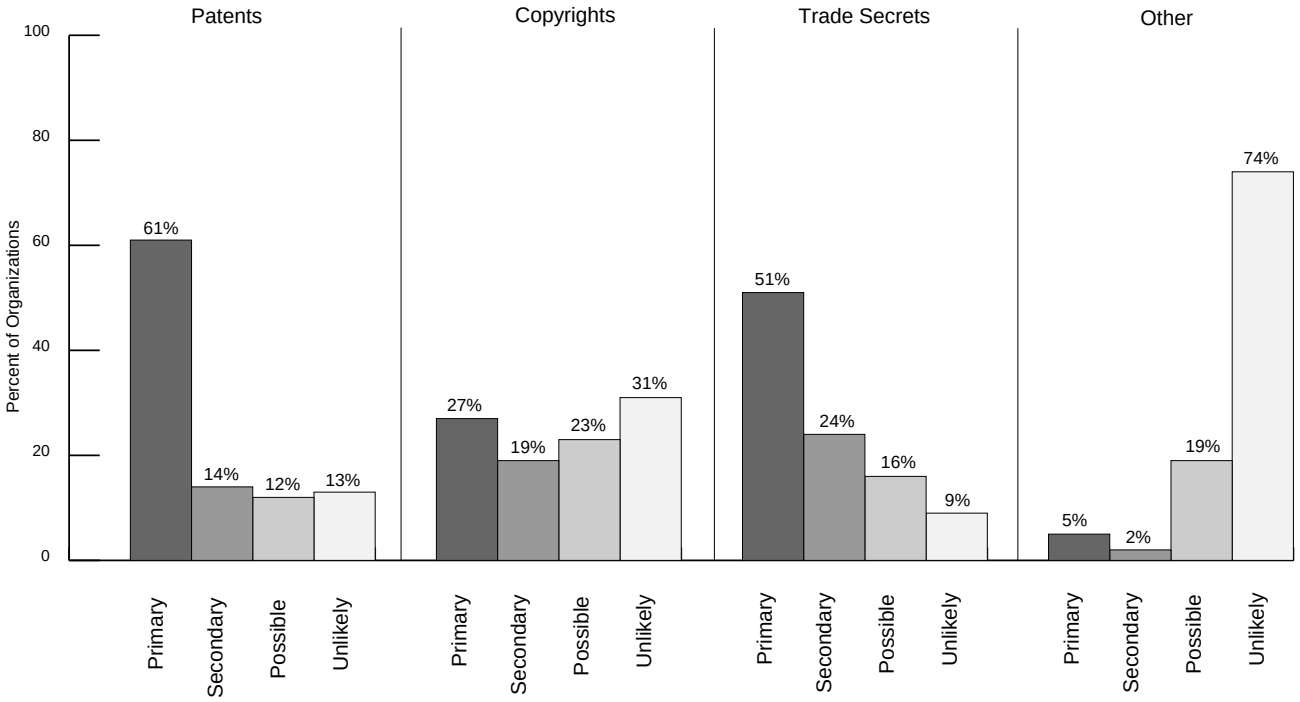
Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded in 1993-1995.

Figure 7. Strategies for commercializing ATP-funded technologies



Source: Business Progress Reports for 778 applications being pursued by 375 companies in 207 ATP projects funded 1993-1995.

Figure 2. Plans for diverse applications of ATP-funded technologies



Source: Business Progress Reports from 480 organizations funded 1993-1995.

Figure 9. Intellectual property strategies planned

protected by patent and other aspects best protected by secret, and thus combine the two strategies.

Organizations receiving ATP awards in the FY 1993–1995 competitions report that the ATP-funded technologies build on, and intellectual property rights are protected by, nearly 2,000 preexisting patents. Companies seeking title to new intellectual property created with ATP funding have reported to NIST 105 new patents filed and 7 copyrights filed; and 11 patents have been issued. Often initial patents predate the ATP project, and the ATP project focuses on bringing the technology beyond a rough concept.

Dissemination of Non-Proprietary Information

Published papers, conference participation, news articles, press releases, and Internet sites provide additional dissemination of information about ATP-funded technologies. Although some companies are more active than others in dissemination, many are very active in publishing papers, issuing press releases, and making public presentations concerning their R&D activities. Universities and other research organizations, with agreement from the for-profit companies holding title to ATP-funded intellectual property, have also been active in disseminating non-proprietary information about their ATP-funded technology development. Table 2 provides a summary of the activity through December 1996 in published professional journal articles and conference papers alone.

According to the BRS data, more than half the projects covered in this study have produced published conference papers, and approximately one-fourth have produced published articles in professional journals. On average, about 1.8 conference papers have been presented and 0.6 professional journal articles published per project.

Conclusions, Related Work, and Future Directions

Findings are that opportunities for economic spillovers from the portfolio of projects in the BRS appear strong, and for the most part consistent with the original peer-review proposal assessments. Project participants have identified more than 1,000 applications of the technologies under development and provided commercialization plans for nearly 800 applications spanning the spectrum of SIC industries. Most applications involve new products with significant performance improvements over existing/defender technologies, offering dramatic possibilities for productivity improvements. Many are "new-to-the-world-products" aimed at brand new markets. Most companies seek to address stages of production relatively early in the production chain, for example, materials processing or component manufacture, creating maximum opportunity for intermediate producers/customers at multiple later stages, and even in multiple application areas, to experience market spillovers.

Opportunities for additional economic spillovers through technology diffusion are being enhanced by patent and licensing activity and dissemination of non-proprietary information. Licensing to others is a primary or secondary strategy for commercializing a large percentage of planned applications, and conference activity and publication of papers have been vigorous.

This paper is based on part of a more comprehensive study that addressed a number of indicators of progress of ATP-funded projects (Powell 1997a). Findings from the 1997 report are largely consistent with the findings of two third-party surveys of projects not in the BRS. Silber & Associates (1996) surveyed projects funded from 1990 through 1992 after approximately two-to-three years of funding. Solomon Associates (1993) surveyed ATP's first competition awardees after just one year of funding. The BRS captures much greater detail than the third-party telephone surveys, explicitly covering the evolution of a myriad of applications. And, of course, the BRS captures the voices of awardees directly without a third party intervening. Although specific summary statistics differ somewhat, analyses of BRS data generally confirm earlier survey results that ATP awards are "enabling [industry] to afford and engage in high risk research," "stimulating collaboration and formation of strategic alliances," "shortening the R&D cycle," "helping attract additional funding," and "creating new business opportunities," among

Table 2. Dissemination of non-proprietary information from ATP-funded projects

	Papers in Professional Journals	Papers Presented at Conferences
Total Number of Papers	131	372
Number of Organizations Reporting Papers	54	154
Number of Projects Reporting Papers	47	110

Note: Across the 208 projects reporting, an average of 0.6 professional journal articles were published and 1.8 conferences papers presented per project. Thirty-six percent of the projects produced at least one professional journal article; 53 percent of the projects produced at least one conference paper.

Source: Business Progress Reports from 210 ATP projects funded 1993-1995.

the many other effects reported by those earlier studies.

Results of the current study are also consistent with and confirmatory of preliminary results given in a recently published conference paper which analyzed data for ATP projects funded in 1993–1995, but with only the 1993 projects (41 companies reporting) having completed at least one year of ATP funding (Powell 1997b).

A study currently underway, using more recent data, features ATP-funded small firms (with fewer than 500 employees) in comparison with all organizations receiving awards in the period 1993 through 1996 (Powell 1998). The study identifies a number of general issues and "strategies for success" for small firms cited in the literature, and it examines the experience of ATP-funded small firms in employing such strategies and considers effects of ATP funding. Findings of the study of a broad array of characteristics and experience of small firms are that small firms are undertaking challenging R&D and pursuing aggressive commercialization goals for a large number of commercial applications, with plans to license for a substantial portion. They seem to be using federal financing to leverage internal company funding, to expand the level, scope, and challenge of their R&D efforts, and to accelerate the R&D process. They are actively engaging in collaboration to achieve their R&D and commercialization goals. They are progressing in early commercialization activities at a pace at least equivalent to the portfolio of all organizations. Together, these characteristics and signs of progress appear to indicate that ATP-funded small firms are pursuing necessary "strategies for success."

Evaluation of the long-run impact of the portfolio of ATP-funded technologies lies in the future. Most of the projects are still at a relatively early stage. Only about 15 percent of the projects covered in the BRS database had been completed at the time data was collected for this paper. Many of the technologies will require considerable additional development and, in the case of medical technologies, undergo FDA regulatory approval before commercialization. The full economic impacts across diverse applications and industries will typically unfold over a number of years—likely a decade or more after the initial ATP-funded research.

As the BRS grows, new types of analyses become feasible. The small-firm study described above represents ATP's first effort to use BRS data to investigate a subset of ATP participants. Future work will (1) extend the BRS to post-ATP project data collection, (2) analyze other ATP subgroups, and (3) use the BRS in conjunction with other data sources to support a variety of evaluation studies, including case studies and econometric analyses.

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ATP's Impact on Accelerating Development and Commercialization of Advanced Technology*

Frances Jean Laidlaw
Motorola, Inc.
Schaumburg, IL 60173

Abstract

One of ATP's legislated mandates is to accelerate industry's development and commercialization of new technologies. This survey of 28 projects funded in 1991 found that ATP helped cut technology development cycle time by 50% in most cases. Slightly more than half of the interviewees provided quantitative estimates of the economic value of reducing cycle time by a single year. Most interviewees expected the positive impact on cycle time experienced in the applied-research stage to flow through to later stages in the technology development cycle allowing them to enter the marketplace more quickly. Cycle-time improvements in other technology development projects were attributed by the companies to their ATP project. Two types of acceleration were implied: (1) overcoming delays in starting technology development projects, and (2) speeding up performance of research once it is under way.

Introduction

This paper is based on a study to evaluate the impact of the ATP on applied research cycle time of companies participating in the program. A larger objective was to determine if the ATP is successfully meeting its legislated mandate to accelerate the development and commercialization of technology. The study focused on applied research cycle time, because high-risk applied research is largely what the ATP funds, and at this still early stage of the ATP that is the period of time most feasible to evaluate. Although there is a large body of literature and an established discipline on improving production cycle time and even product-development cycle time, this is not the case for applied-research cycle time. The investigation of applied-research cycle time is a relatively new and emerging discipline.

Previous studies of the ATP found that participants reported that the program had the effect of shortening their research and development (R&D) cycle time. Solomon Associates, in a 1993 report, found that sixty-nine percent (69%) of the first group of ATP awardees reported a significant shortening of the R&D cycle. Silber & Associates, in a 1996 report, found for 125 ATP participants funded between 1990 and 1992 the following: (1) 95% of participants believed that the ATP award accelerated their progress; (2) 74% anticipated shaving off a minimum of two years from the R&D cycle; and (3) 81% described speed to market as critically important or very important.

The primary purpose of the case study on which this paper is based was to gain a clearer understanding of issues pertaining to acceleration of technology development and commercialization.

Within the company setting, the main source of cycle-time reduction strategies has traditionally been operations. Typically, cycle-time reduction (CTR) started in manufacturing and then migrated "downstream" to sales and distribution. A question is whether the ATP can start at the applied research end and stimulate time reductions that will propagate forward, from the research cycle through the production and marketing cycles.

Why Reduce Cycle Time?

McGrath, Anthony and Shapiro stated:

> If manufacturing and total quality management were viewed as the industrial battlegrounds of the late 1970s and 1980s, product development and cycle-time reduction are the battlegrounds of the 1990s. The advantages that come from reducing time to market and consistently developing better products are so significant that they will shift the competitive balance in favor of companies that can achieve them first. A company that can efficiently introduce more new products, react faster to market and technology changes, and develop superior products will win battles with its competitors. The key to achieving these advantages is improving the product development process and

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getting to market more quickly. This is why it will become the battleground of the 1990s (McGrath, Anthony, & Shapiro 1992).

Though most of the articles to date on reducing R&D cycle time focus more on the "D" (development) than the "R" (research), an article that highlights industry's increasing interest in reducing applied research cycle time is Bob Burkhart's "Reducing R&D Cycle Time," prepared for the Industrial Research Institute (IRI). It states that research at the "fuzzy front end" carries high uncertainty; and successful output cannot be readily scheduled, as with the development phase. Only after identifying the potential causes for uncertainty in the decisions and activities of the research phase might barriers be reduced or removed by applying appropriate solutions; for as knowledge grows, risk recedes and the capacity to advance in a shorter time frame materializes.

Research Design

The study assessed the impacts on cycle time of participating in the ATP, based on a telephone survey of the twenty-eight 1991 ATP awardees. The 28 awardees surveyed included 18 single company awardees and the lead organization of each of 10 joint venture projects. Together, the 28 projects in the sample comprised 10% of the projects the ATP had funded as of the time the study was performed. Interviewees were encouraged to be candid and forthright with their responses. They were assured that their individual responses would be without company or personal attribution.

As shown in the taxonomy in Table 1, the 1991 ATP awardees can be classified in four major technology arenas: advanced materials, electronics, biotech and manufacturing technologies. Interviewees included those from small for-profit companies, medium- and large-sized for-profit companies, as well as nonprofit industry consortia. In evaluating the impact that the ATP program had on company applied research cycle time, the following eight questions were asked of the principal investigator for each project:

1. How important is it for your company to reduce cycle time (time to market)?
2. Why is it important for your company to reduce applied research cycle time?
3. How much (by what percent change) did participation in the ATP affect your ATP project's applied research cycle time?
4. Do you expect the impact on cycle time in the applied research stage to flow through to other stages in the technology development life cycle?
5. Can you give a ballpark estimate of the economic value of reducing your cycle time by one year?
6. How were the cycle time improvements achieved (i.e., what did you do differently as a result of participating in ATP)?
7. Did the cycle time improvements (that were a result of participating in ATP) carryover to other technology development projects outside of the ATP project?

Research Results

The research results describe the impact that the ATP program had on the 28 awardees from the 1991 competition, as related by the principal investigator of each project's lead organization. No attempt was made to generalize the results beyond the particular cases studied.

The Importance of Reducing Applied Research Cycle Time

Twenty-seven, or 96% of the 28 interviewees, indicated that it was "very important" for their companies to reduce cycle time, while 1 (4%) indicated that it was "important." These results are consistent with findings from an open literature review that found that cycle-time reduction was viewed as important because it enhances a company's global competitiveness and helps a company to better achieve its performance goals. These results are also consistent with (though not identical to) findings from other studies.

Reasons to Reduce Applied Research Cycle Time

When the 28 interviewees were asked "Why is it important for your company to reduce cycle time?" most gave more than one reason. There is obvious overlap among the types of reasons given, but in order to preserve the flavor of the responses, these were kept separate rather than grouped under umbrella headings:

1. Meet Competitive Challenge [12 interviewees]
2. Satisfy Customers [9 interviewees]
3. Attract Additional Capital [8 interviewees]
4. Enhance Technology Development Process [7 interviewees]
5. Reduce Costs [6 interviewees]
6. Survive [5 interviewees]
7. Enhance Quality [5 interviewees]
8. Increase Return on Investment (ROI) [5 interviewees]
9. Respond to Changing Market [3 interviewees]
10. Dominate Market [3 interviewees]
11. Reduce Risk [3 interviewees]
12. Grow [2 interviewees]
13. Increase Sales Volume [2 interviewees]
14. Increase Market Share [2 interviewees]
15. Combat Perceived Weakness [2 interviewees]
16. Develop Critical Capability [2 interviewees]
17. Take Advantage of Window of Opportunity [2 interviewees]
18. Collaborate [2 interviewees]

Table 1. Taxonomy of 1991 interviewees

Technology and Type of Lead Organization	Organization
Ten (10) Advanced Materials	
· 3 Small Companies	Cree Research, Inc., Nanophase Technologies Corp., Spire Corp.
· 3 Medium/Large Companies	Armstrong World Industries, Allied Signal Aerospace, IBM Corp.
· 3 Medium/Large Companies Leading JVs	Ford Motor Co., Honeywell, Westinghouse Electric Corp.
· 1 Non-Profit Research Institute	Michigan Molecular Institute
Nine (9) Electronics	
· 4 Small Companies	American Superconductor Corp., AstroPower, Iterated Systems, X-Ray Optical Systems
· 2 Small Companies Leading JVs	Conductus, Inc., Spectra Diode Laboratories
· 2 Non-Profit Consortia Leading JVs	American Scaled-Electronics Consortium, National Storage Industry Consortium
· 1 Non-Profit Consortium	The Microelectronics Center of North Carolina
Five (5) Biotech	
· 5 Small Companies	Aastrom Biosciences, Aphios, Biosym Technologies, BioSys, Engineering Animation
Four (4) Manufacturing	
· 1 Small Company	Transitions Research Corp.
· 3 Non-Profit Consortia Leading JVs	Auto Body Consortium, National Center for Manufacturing Sciences, South Carolina Research Authority

19. Choice of Competitive Strategy [2 interviewees]
20. Maintain Technical Leadership [1 interviewee]
21. Establish Intellectual Property Rights [1 interviewee]
22. Follow Industry Practice [1 interviewee]

The finding that the most frequently given reason to reduce applied research cycle time was to meet competition is consistent with the paramount finding from the literature review that cycle-time reduction is important because it enhances global competitiveness. Other research that has explored the relationships among technical content, innovation, cycle time, and break-even time, has found that increasing technical content and degree of innovation has strong delaying effects on cycle time. As postulated by Powell (1998), ATP's acceleration of cycle time may to some extent offset the negative effects of innovation on cycle time.

Impact of ATP Participation on Applied Research Cycle Time

To the question, "How much (by what percentage change) did participation in the ATP affect your ATP project's applied research cycle time?" the median response of the 28 interviewees was that participation in ATP reduced their ATP project cycle time by 50% or 3 years (see Table 2). The median response was that without ATP, the same project would have taken 6 years. In terms of years saved, the range was from 1 to 2 years at the low end, to 10 years and more (infinity) at the high end. In terms of percentage cut in cycle time, the range was 25% to 80%.

Five of the 28 interviewees challenged the question. They said that a more relevant question was "Would you have done the applied research at all without ATP support?" They attributed the entire existence of the project to participation in ATP, with an "infinite" impact on the applied research cycle time. As one interviewee stated: "The business environment is now more short sighted. It is more hesitant to put capital into technology development projects and to apply technology once it is developed. Given the past three-to-four years, it's fair to say we wouldn't have started or pursued this research without ATP funding." These five interviewees, which included companies of all sizes, said they could not bound the reduction in applied research cycle time because they would not have ever begun without the ATP award.

It is interesting that many of the interviewees' responses to this question are so similar, particularly since

Table 2. Impact of ATP participation on applied research cycle time

Rank Order by % Reduction	% Reduction	Number of Years Shorter
(1) small	*	unbounded
(2) small	*	unbounded
(3) medium/large	*	unbounded
(4) medium/large	*	unbounded
(5) medium/large	*	unbounded
(6) small	75 to 80%	10 years shorter
(7) medium/large	66-75%	6 to 9 years shorter
(8) small	50-66%	5 to 6 years shorter
(9) small	50-60%	at least 5 years shorter
(10) small	50%	5 to 6 years shorter
(11) small	50 %	5 years shorter
(12) small	50%	5 years shorter
(13) medium/large	50%	5 years shorter
(14) small	**50% MEDIAN**	**3 years shorter**
(15) small	**50% RESPONSE**	**3 years shorter**
(16) medium/large	50%	3 years shorter
(17) medium/large	50%	3 years shorter
(18) medium/large	50%	3 years shorter
(19) medium/large	50%	3 years shorter
(20) medium/large	50%	3 years shorter
(21) medium/large	50%	2 years shorter
(22) medium/large	50%	2 years shorter
(23) small	50%	1.5 years shorter
(24) small	50%	1.25 years shorter
(25) small	33-50%	1 - 2 years shorter
(26) small	33%	2 years shorter
(27) medium/large	30%	3-5 years shorter
(28) medium/large	25%	2 years shorter

*These companies were unwilling to bound their estimated cycle-time reductions because they said they wouldn't have ever started without the ATP award.

the interviewees come from different kinds of organizations, different sizes of organizations, and different types of industries.

Flow-Through of ATP's Impact on Applied Research Cycle Time to Later Stages in the Technology Development Life Cycle

When asked, "Do you expect the impact on cycle time in the applied research stage to flow through to other stages in the technology development life cycle?" 24 (86% of the 28 interviewees) said yes. One interviewee suggested that this is better described as a cascade effect, not a flow, since it is not linear. He described it as a driving force that has a broad effect. This implies that, at least in some cases, speeding up the R&D may have a disproportional impact on the later stages in technology development.

Of the four interviewees who did not give a clear yes to the question, one said "probably yes," but that he wasn't sure, and three said that it was not applicable. Two of those provided the following reasons for the lack of applicability of the question: According to one, "We only do technology development. We get a commercial partner interested and transfer technology to them. The intellectual property revenue stream seeds and funds internal R&D" According to the other, "The applied research only advanced to the demonstration stage. That's when market analysis revealed that new competitive challenges in the marketplace had rendered our applied research obsolete. As a result, we did not advance the applied research beyond the demonstration stage."

A careful review of the literature did not yield many articles that touched specifically on the flow-through of applied research cycle-time savings to later stages in the technology development cycle. Most of the R&D evaluations conducted by industry, government, academia, and science over the past four decades have focused on the short-term; few studies have directly linked research inputs to research outputs and research outcomes.

If there were neither flow-through nor linkage between research cycle-times and the time required for commercial outcomes, then there would be no marketplace benefit associated with reducing applied research cycle time. If, on the other hand, there is a flow-through or linkage, then the potential for accelerated long-run economic benefits exists from shortening the research phase. Common sense would cause us to expect a flow-through of time savings from the earlier stages to the later stages, and, indeed, the study found that most of the interviewees expected the impact on research time to flow through to later stages in the technology development and commercialization cycle. Though the study made the anticipated linkage, the impact of earlier-stage time savings on the timing and size of longer-term outcomes needs to be more fully explicated.

Economic Value of Reducing Applied Research Cycle Time By One Year

When asked, "Can you give a 'ballpark estimate' of the economic value of reducing applied research cycle time by one year?" 22 (79% of the 28 interviewees) gave either a quantitative or qualitative "ballpark estimate." Fifteen, or 54% of the 28 interviewees, gave a *quantitative* estimate.

The estimates range from one million dollars to "billions" for a one-year reduction in applied research cycle time, and for the most part appear to relate specifically to the direct economic values to the company or JV member companies rather than to the potential additional benefits that might be realized by accelerating economic spillover effects. The estimates in Table 3 are listed in order of the size of the value, with the largest estimated value listed first. The median estimate of the economic value of reducing the applied research cycle time by just one year is $5 million to $6 million.

ATP Effects that Helped Reduce Applied Research Cycle Time

When the 28 interviewees were asked "How were the cycle-time improvements achieved; in other words, what did you do differently as a result of participating in ATP?" they gave 58 answers. When the answers are grouped by the type of ATP practice that helped interviewees reduce cycle time, we find that there are five major ATP categories. Table 4 shows aggregate total frequencies and percentages.

1. ATP's Required Project Planning and Management [15 interviewees]

For this sample of 28 interviewees representing 28 projects from the 1991 competition, the detailed project planning that ATP required and the project management it provided to ensure that companies followed the project plan were most frequently cited as the ATP effect that helped interviewees to reduce cycle time. It was felt, in general, that the well laid-out plan required by ATP from the companies lent stability to the applied research program. According to one interviewee: "Of greatest value, with ATP we had a well-laid-out plan, and followed the plan without interruption. Without the ATP plan, the vagaries of our business would have caused us to vary the plan. If we were not having a good year financially, we would probably have pulled the plug—but ATP's involvement lent stability to the research program." ATP's requirement for an integrated business and R&D plan with its emphasis on concurrent engineering seemed to speed things up. This was described by one interviewee: "For us, product testing typically comes later in the product development cycle. ATP wanted us to work early-on with potential customers and users. One of our primary interests from the very beginning was to work with potential users. We wanted to work in a 'true manufacturing envelope' with 'true manufacturing equipment.' ATP made this happen." Other

Table 3. Ballpark estimates of economic value of a one-year reduction in applied research cycle time, in order of decreasing value

Type of Organization	Economic Value of Getting to Market One Year Sooner	Nature of the Economic Value
(1) medium/large	$100's of millions to billions	sales revenue
(2) medium/large	$1 billion	sales revenue
(3) medium/large	$100 to 200 million	sales revenue
(4) small	$15 to 250 million to ultimately ½ billion	sales revenue
(5) small	$10 to 100 million	sales revenue
(6) small	$10 to 30 million	sales revenue
(7) medium/large	$15 million	sales revenue
(8) small	**$5 million to $6 million MEDIAN VALUE**	**sales revenue**
(9) small	$5.2 million	capital cost savings
(10) medium/large	$2 to 5 million	sales revenue
(11) small	Millions of dollars	sales revenue
(12) small	Millions of dollars	sales revenue
(13) small	Millions of dollars	sales revenue
(14) medium/large	$2 million	sales revenue
(15) small	$1 to 2.25 million	sales revenue and cost savings

project planning and management techniques that were said to be important to cycle-time reduction and attributed to the ATP involvement included: using a systematic approach; developing definable time lines and value; benchmarking and selecting technology applications; integrating the voice of the customer; assuring quality; and enhancing documentation procedures.

2. Achievement of a Critical Mass of Resources Through ATP Funding [12 interviewees]

ATP funding was important to applied research cycle-time reduction because it enabled interviewees to gain the critical mass of resources necessary to conduct the applied research. This was mentioned by interviewees from small for-profit companies, medium-to-large for-profit companies, and nonprofit consortia. For most interviewees, this meant increasing staffing, but a couple mentioned material resources, and one said that the company was able to more fully dedicate existing staff to the applied research project. An interviewee from a large company stated: "Major companies are structured into decentralized divisions—each little fiefdom (division) has a budget. Our division didn't have adequate funding to pursue this project." An interviewee from a small company stated, "ATP enabled us to acquire a critical mass of resources. The corporation has

Table 4. ATP effects that helped interviewees reduce cycle time

Effect	Frequency of Mention	%
ATP's Required Project Planning and Management	15	25.86%
Achievement of Critical Mass of Resources with ATP Funding	12	20.69%
Attraction of Additional Financial Support through ATP "Halo Effect"	12	20.69%
Greater Project Stability through Focus on Technical Problem	12	20.69%
ATP's Emphasis on Collaboration	7	12.07%
TOTAL	58	100.00%

limited resources. We looked around. We wouldn't have had enough resources to reach critical mass to develop and leverage resources. As a small company, we wouldn't have been able to do the R&D, period."

3. Attraction of Additional Financial Support through ATP "Halo Effect" [12 interviewees]

Some interviewees mentioned their improved ability to stimulate interest and acquire capital to continue pursuing their advanced technologies as an important ATP effect on cycle time. The additional infusion of capital was said by some to have been critical. Many of the scientists and engineers appear to have taken on an entrepreneurial role to support and speed the development of their technology.

A few of the comments about the effect of attracting additional capital on reducing applied research cycle time follow: "There is a question in our minds as to where we would have gotten funding, and a question as to whether we would have survived. We didn't round up private funding until after we got ATP funding. It's a high-risk project, and we had previously operated by bootstrapping, which would not have lasted long." "If we had not had ATP funds, we would have had to attract capital. That would have been difficult without ATP. With ATP, we got press and were able to generate excitement. It easily halved the development time." "We were able to leverage ATP participation to quickly acquire additional funding. Selection as an ATP project resulted in the perception that we were a viable organization. We were able to get new venture capital for other technology projects, programs, and platforms."

4. Greater Project Stability Through Focus on Technical Issue [10 interviewees]

Six interviewees commented that participating in the ATP enabled them to shorten the applied research cycle time by allowing them to concentrate on solving the technical problem.

One large company interviewee said, "The ATP contract allowed an R&D group to do enough work on a technology to go to other people in a large company with more than a prototype. The company was reducing the R&D budget and manpower; and the ATP support was critical because it allowed us to focus on the technology problem, rather than the organizational problem." Another large company interviewee said, "The technology development wouldn't have happened without ATP. The ATP was really a catalyst. The match was not only important from a financial standpoint but from a strategic standpoint as well. What is most difficult for us in a large bureaucracy is to get the snowball started and that's what ATP helped us to do." A small company interviewee said, "The ATP gave us the ability to make certain mistakes in research—participating allowed us to proceed in an orderly, 'unpanicked' way."

5. Enhanced Collaboration [6 interviewees]

Six interviewees said ATP enhancement of collaboration helped reduce the applied research cycle time. Four interviewees explained that: "ATP brought strange bedfellows together—who were competitors. ATP also brought members of the supply chain together to define what they needed in the supply chain. As a result, it helped us and other members of the supply chain to move further, faster." "Perhaps most importantly, ATP brought competing companies together. This would not have otherwise happened. They never would have worked with each other without ATP. Within mega-corporations, there is oftentimes much personal competition between the senior executives. The benefit of a joint venture is that senior executives from different companies are sometimes more willing to share ideas with executives from other companies than with peers in their own organization. This enhances the innovative thinking and collaborative processes. The members of the ATP joint venture were so compatible with each other that they moved smoothly like a dance team—it got to the point that in meetings that they were building on each other's words and finishing each other's sentences." "Beyond enhancing collaboration between competitors, ATP enhanced collaboration between technology developers and technology purchasers. We developed the technology in a joint venture partnership. Two of our partners didn't want to buy R&D directly from us, but they wanted to invest in our technology development under the auspices of ATP." "Through ATP, we structured a mutual win-win with a joint venture partner that had a complementary set of technology skills that enabled both of us to develop the technology more quickly."

The finding that ATP's required project planning and project management support was mentioned more frequently than its funding support for this particular sample of program participants, though not statistically significant, is suggestive. It highlights one of the unusual characteristics of this governmental program: it does more than disburse funds, it requires both R&D and business advance project planning, and it monitors project progress against both technical and business goals, over the multi-year project life. ATP views the companies as partners in the technology development process and takes an active role in overseeing how the projects are carried out. As a result, the relationship between the "partners" (ATP and the awardee organizations) entails a detailed technical and business review by ATP of the proposed project, with feedback to the proposers; rigorous competition among proposers against published selection criteria; and a kickoff meeting where technical milestones and business goals are further reviewed and detailed. The kickoff meeting is followed by quarterly reports and annual reviews until the project is completed. Failure to perform can lead to project termination. Then, there is post-project tracking of further developments. This active participative role appears to be the reason why ATP was viewed by the interviewees as strengthening their planning for technology development, enhancing strategic focus, and providing stability to see the job through.

It is interesting to note that there are two types of acceleration implied in the responses. One relates to overcoming delays in starting technology development projects. The other relates to speeding up performance of the re-

Table 5. Carryover of cycle-time improvements to other projects

Type	Carryover of Cycle-Time Improvements	Frequency	%
(1)	Yes - Enabling, Generic, Precompetitive Technology	9	32.14%
(2)	Yes - Adopting "ATP Practice" to Related Projects	6	21.44%
(3)	Yes- Extended Adoption of New Methodologies and Processes	4	14.29%
(4)	Yes- Cultural Change	2	7.14%
(5)	Yes - A Little	3	10.71%
(6)	No	3	10.71%
(7)	Don't Know	1	3.57%
	Total	28	100.00%

search once it is underway. The ATP funding seems to have played a critical role in overcoming the inability to get the projects off the ground. The advance technical and business planning requirements, project oversight to hold it on course, and research efficiency gains from collaboration—in addition to the funding—seem to have been critical factors in speeding up the research once the projects began.

Carryover of Cycle-Time Improvements Resulting from ATP Participation to Non-ATP Applied Research Projects

When the 28 interviewees were asked, "Did the cycle-time improvements that were a result of participating in the ATP carry over to other technology development projects?" 24, or 86% of the 28 interviewees, said yes; 3 (11%) said no; and 1 (3%) said they didn't know if cycle-time improvements "carried over." Most of the interviewees explained ways in which the ATP-fostered cycle-time reductions were transferred to other technology development projects. These responses are listed in Table 5, grouped by nature of response and placed in order of total frequency of mention.

1. "Yes, Enabling, Generic, Precompetitive Technology" [9 interviewees]

Nine interviewees, or 32% of the sample, said that cycle-time improvements that were a result of participating in ATP were carried over to other technology development projects because the ATP resulted in an enabling technology that had broader applications that allowed them to speed up other projects. Two different interviewees explained this well: The first said, "Through ATP, we built a better understanding of technology. We can spin-out products at a faster rate because we have a fundamental understanding of core technology with multiple applications." The second said, "It turned out that the technology we were developing through ATP had utility for other applications. It has become a technology platform for other applications" (Note that this effect could also be viewed in the context of intra-firm spillovers and economies of scope.)

2. Adopting "ATP Practice" to Related Projects [6 interviewees]

Six (6) interviewees, or 21% of the sample, said that cycle-time improvements resulting from their ATP participation were carried over to related projects within the company, with other government organizations, and with industry because they are applying ATP-required planning and project management practices to other projects. One interviewee explained: "Our organization has changed. We were once a small independent research entity—but things have changed significantly. We've received a large contract from industry. . . . The ATP cultural imperative and requirement that experiments be written up in a rigorous fashion did have an impact—we are giving the write-ups to an archivist; and we are using similar methods on our industrial contract. We do not have a separate quality assurance department, but following the ATP practice, we have embedded quality into our day-to-day work habits."

3. "Yes, Extended Adoption of New Methodologies and Processes" [4 interviewees]

Four (4) interviewees, or 14% of the sample, reported that cycle-time improvements were enabled by the adoption of new methodologies and processes resulting from their ATP participation. As one interviewee explained, "Peer pressure being what it is, once two groups come up with a way to reduce cycle time—others immediately find out what is going on and apply the new methodology to their own group." As another explained, "We used ATP funds to do process development. It was a building block for other developments. We now have a reliable base to build on and benefit from the cumulative effects."

4. "Yes, Cultural Change" [2 interviewees]

Two (2) interviewees, or 7% of the sample, believed that the cycle-time improvements that were a result of participating in ATP resulted in a cultural change that carried over to other projects. As one stated, "By doing this on a faster speed in the ATP project, we built a culture that expects to do things faster. By focusing on long-term needs,

it allowed us to better manage short-term needs."

5. "Yes, A Little." [3 interviewees]

Three (3) interviewees, or 11% of the sample said, "Yes, the cycle-time improvements were carried over 'a little,' in other words, to a minimum extent," but didn't elaborate as to how.

6. "No, No Change." [3 interviewees]

For the three (3) interviewees, or 11% of the sample, who said that cycle-time improvements were not carried over, they attributed the lack of carryover to internal organizational dynamics. For example, one interviewee stated: "No—but our company is going through a series of changes—we're restructuring every operation into decentralized units. The company is breaking up into smaller units. This reduces opportunity for cross-fertilization. In another organization with a more centralized research system, more benefits could have been derived. This is frustrating because the potential existed but could not be realized."

7. "Don't know." [1 interviewee]

One interviewee, or 3.6% of the sample, said they didn't know if there was a carryover to other projects.

When ATP practices result in cycle-time improvements that are carried over, we can say that to some extent, these practices have been institutionalized. In fact, this study found that the representatives for the lead-company awardees thought that ATP-originated practices were, for the most part, carried over, (hence institutionalized). Interviewees attributed the carryover to the enabling technologies that positioned the companies to execute a number of subsequent spin-off activities faster; to the use on related projects of ATP-acquired practices that foster project acceleration; to the wider application of new methodologies and new processes that reduce cycle time; and to cultural changes associated with adopting a faster pace as a way of life. They discussed how participating in the ATP program enabled them to remove organizational barriers to cycle-time reduction. But beyond brief characterizations, they did not provide much detail. To the extent that other work in the ATP-funded companies was accelerated by the companies' participation in the ATP, the benefits of ATP on the participating companies may be systemic in nature and greater than anticipated.

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Author Biography

Frances Laidlaw is a manager in R&D at Motorola specializing in technology planning. She holds a doctoral degree in Engineering, an M.B.A. from Columbia University, and a B.A. from the University of Illinois. Before joining Motorola, she was a Fulbright fellow conducting post-doctoral research at the University of Paris; and before that, a doctoral student at George Washington University, and a consultant-on-staff in the Advanced Technology Program at the National Institute of Standards and Technology.

Case Study of R&D Efficiency in an ATP Joint Venture

Albert N. Link
University of North Carolina at Greensboro
Greensboro, NC 27412

Abstract

This paper summarizes the technical accomplishments and presents selected measures of research efficiencies and early stage economic impacts of the Printed Wiring Board (PWB) Research Joint Venture Project. The project was cost-shared by the Advanced Technology Program and carried out by a group of seven companies, with participation by Sandia National Laboratories. The period considerred in this case study is from mid-1991 through mid-1996, the time during which the research was conducted.

ATP's funding of the PWB Research Joint Venture has thus far had a number of direct and indirect economic impacts. Of the direct impacts, the largest to date has been the increase in R&D efficiency. The project achieved at least a 53 percent reduction in overall research costs. The increase in research efficiency has 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.

Introduction

The ATP Award to the Printed Wiring Board Research Joint Venture

In April 1991, ATP announced that one of its initial eleven awards was to a joint venture led by the National Center for Manufacturing Sciences (NCMS). The objective of the project was to research aspects of printed wiring board (PWB) interconnect systems. A printed wiring board (PWB) or printed circuit board (PCB) is a device that provides electrical interconnections and a surface for mounting electrical components. The project was completed in April 1996. Actual ATP costs (pre-audited) amounted to $12.866 million over the five-year (statutory limit) funding period. Actual industry costs amounted to $13.693 million. During the project the U.S. Department of Energy added an additional $5.2 million. Thus, total project costs were $31.759 million. As part of its evaluation effort, the ATP wanted to understand better the working of the joint ventures it funded. It commissioned two studies of the Printed Wiring Board (PWB) Joint Venture, the first in 1993, two years after the joint venture began; and a second in 199 , soon after the project ended. This paper reports the results of those studies (Link 1993, 1997).

Trends in the Competitiveness of the PWB Industry

The United States dominated the world PWB market in the early 1980s. However, Japan steadily gained market share from the United States. By 1985, the U.S. share of the world market was, for the first time, less than that of the rest of the world excluding Japan; and by 1987 Japan's world market share surpassed that of the United States and continued to grow until 1990. By 1994, the U.S. share of the world market was approximately equal to that of Japan, but considerably below the share of the rest of the world, which was nearly as large as the two combined. While there is no single event that explains the decline in U.S. market share, one very important factor, at least according to a member of the PWB Project team, 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 (Council on Competitiveness, 1991). 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."

In 1994, the Council 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 (Council of Competitiveness 1994). Recently, industry spokespersons have heralded signs of an industry turnaround in the industry.

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Table 1. 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

Note: Funding under the ATP award to the PWB research joint venture commenced in April 1991. The ATP funding period ended in April 1996.

Roles and Relationships among Members of the Joint Venture

Membership of the PWB Joint Venture, in addition to NCMS, and changes in the membership over the course of the project are summarized in Table 1. 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.

Three companies joined the joint venture to assume DECs research responsibilities: AlliedSignal in 1993, and Hughes Electronics and IBM in 1994. Also, Sandia National Laboratories became involved in the joint venture during 1992, as anticipated when NCMS submitted its proposal to ATP for funding. Sandia subsequently obtained an additional $5.2 million from the Department of Energy to support the research effort of the joint venture.

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 (Link & Bauer 1989). This conclusion is supported in the case study here, as evidenced by the quantitative estimates of cost savings reported by the members, and by the specific case examples cited in support of the cost-savings estimates.

Table 2. 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 PWB's 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.

Characteristics of the joint venture member companies are summarized in Table 2. AT&T, Hughes, IBM, and Texas Instruments were four of the leading domestic captive producers of PWBs when the project began; they were also members of NCMS, the joint venture administrator. Although in the same broadly-defined industry (i.e., they are horizontally related), two of these companies, 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. Although Hughes and Texas Instruments produced for different niche markets, they did compete with each other in some Department of Defense areas. Hamilton Standard, no longer a producer, purchases boards to use in its production of engines and flight control electronics. AT&T and Texas Instruments are not involved in these latter two product areas. In contrast to all of the other companies, AlliedSignal is a major supplier of materials (e.g., glass cloth, laminates, resins, copper foil) to the PWB industry. In addition, it is a small-scale captive producer of multilayered PWBs.

Organizational Structure of the Joint Venture

A Steering Committee, with a senior technical representative from each of the participating organizations worked collectively to direct and control the four research teams to ensure that each was meeting the technical goals of the project. NCMS provided the program management, coordination, facilitation, and interface with ATP for the PWB project. NCMS coordinated and scheduled activities and provided the interface between the administrative functions of accounting, contracts, and legal functions related to intellectual property agreements.

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 of senior managers who were paying the bills.

The joint venture's research activities were divided into four components:

- Materials
- Surface Finishes
- Imaging
- Product (research; not product development).

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 these four components of the PWB business. 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 components. The four research teams were involved in 62 separate tasks.

Each team 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. These test methods can be applied during fabrication to ensure the PWB meets assembly quality requirements.

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. Based on input from the industry which revealed that this was not the best research path to take, its focus changed as did its name. The revised goal of the Product Team, after studying roadmaps and specification predictions, was to develop high density interconnect structures. (The Product Team, like the other teams, carried out research.)

Given the generic research agenda of the joint venture 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, among many other things, the following: (1) the Materials Team developed the technology for making single-ply laminates and a new, dimensionally stable thin film material that has superior properties to any other material 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 successfully demonstrated the process required to obtain a yield of greater than 98 percent for 3 mil line and space features; and (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

The conceptual approach to the assessment of early economic gains from this joint venture parallels the approach used by others in economic assessments of federally supported R&D projects (see Link 1996b). Specifically, a hypothetical counter-factual survey experiment was conducted. Participants in the joint venture were asked to quantify a number of related metrics that compared the current 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 joint venture. Additional questions were also posed to each team leader in an effort to obtain insights about the results of the joint venture affecting the industry as a whole.

In a 1993 study (Link 1993), it was determined that only 6.5 of the 29 then ongoing tasks in the PWB Joint Venture would have been started in the absence of the ATP award. At project end, there were 62 research tasks, and it was estimated that about half of these would not have been started in the absence of ATP funding. (The number of research areas increased from 29 to 62 as the companies worked together and identified new problems and tasks to solve them.)

A counter-factual survey was created to examine that subset of tasks that would have been started even in the absence of ATP support. Each of the project team leaders was briefed about this study at the April 1996, end-of-project Steering Committee meeting. It was decided that the survey would focus on only one limited 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 anyway 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. And, estimates of quantified impacts would represent a lower bound estimate of actual economic value of the joint venture. On the negative side, a number of technical accomplishments that would not have come about but for the joint venture have the potential in time to generate large economic benefits to the PWB industry and to consumers of PWB-based products. No aggregate estimate of the potential value of these impacts was attempted in this study due to its early nature, though examples of productivity impacts currently realized by several of the companies were documented. Looking at developments several years downstream should shed more light on diffusion of the technology developed in the project and their benefits in use.

Methodology for Data Collection

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 then only be provided for the study in aggregate form. 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 Workyears 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
- Productivity Increases in Production.

The survey also considered these two broad categories of indirect impact:

- Technology Transfer to Firms Outside the Joint Venture
- International Competitiveness Issues.

Focused survey findings were supplemented with selected open-ended comments offered by respondents; by personal discussions with team leaders and company representatives during the April 1996, Steering Committee meeting; and by follow-up telephone and electronic mail discussions with available members.

Survey Results: Two Snapshots in Time, 1993 and 1996

All members concurred that the joint venture would not have formed by them or by others in industry in the absence of ATP funds to leverage the overall research program. Each member of the PWB research joint venture was asked which research tasks in which they were involved would have been started by their company 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 either because of the cost of such research or because of the related risk. Tasks that would not have been started without ATP funding include:

- Development of alternative surface finishes
- Projection imaging evaluations
- Revolutionary test vehicle designs
- Plasma process monitoring equipment
- PTH modeling software, and also
- 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 at least one year for financial reasons.

Direct Impact on Member Companies

Regarding the five categories of direct impacts:

1. *Scale, Scope, and Coordination Efficiencies: Estimated Workyears Saved By Carrying Out the Research as a Joint Venture*

Two years into the project, the members estimated a total of 79 workyears had been saved from avoiding redundant research, valued at more than $10 million (Link, 1993). At the end of the project, the members estimated a total of 156 workyears had been saved. The total value of these workyears 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 research tasks that they have been willing to conduct individually in the absence of the ATP joint venture were in fact actually carried out individually and without collaboration (see Link, Teece, & Finan 1996 for related examples of labor savings from joint venture research).

An example of workyears saved by avoiding redundant research was provided by a member of the Steering Committee:

> 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 this joint development and sharing by avoiding redundant research time and expenses.

2. *Testing Materials and Machine Time Savings*

Two years into the project, the members estimated cost savings to be over $2 million from saving in research testing materials and research machine time. At the end of the project, the members estimated the total value of savings in research testing materials and machine time 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 the 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 workyears 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, the members estimated that shortened time to put new procedures and processes into research practice was realized from about 30 percent of the tasks, and the average time saved per research task was nearly 13 months. At the end of the project, the 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 the potential revenue gains associated with shortened time to practice.

As an example of shortened time to put into practice new procedures and processes, 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 Increase in Production*

Two years into the project, members of the Steering Committee estimated that participants in the project 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 productivity gains in production which could be traced to research developments in about 40 percent of the 62 research areas. It was not possible to segment productivity improvements attributable to the group of research projects that would have been undertaken absent ATP funding from those that would not have been undertaken, due to the complimentary effects of research project results on production 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 has 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 member of the Steering Committee 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 example of productivity improvement relates to dimensional stability. In particular, another member of the Steering Committee noted:

> The inability to accurately predict inner layer shrinkage leads to a serious compromise with interconnection density and often leads to costly scrap. At the beginning 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

Two categories of indirect impact were identified which already are beginning to extend beyond the member companies to the entire industry: advanced scientific knowledge important to making PWBs, and improvements in international competitiveness. For these types of impact, descriptive information was collected to illustrate the breadth of the impact, but no effort was made to estimate aggregate dollar value or to segment them according to 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 attempting aggregate dollar valuations at this time would be extremely speculative in nature.

1. Technology Transfer to Firms Outside the Joint Venture

Two years into the project, the members estimated that 12 research papers had been presented to various industry groups; 40 professional conferences fundamental to the research of the joint venture had been attended; information from the research tasks was shared with about 30 percent of the industry supplying parts and materials to the PWB industry; and personal interactions had occurred between members of the Imaging Team and suppliers of resist materials to the industry.

At the end of the project, a total of 214 papers related to the research findings from the PWB project had been presented, 96 at professional conferences and 118 at informal gatherings of PWB suppliers and at other forums. Additional papers were scheduled for presentation at the time of this study.

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.

Members of the Materials Team attended 10 conferences at which 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, as of the end of the project, of these technology transfer efforts. While all thought that they were important to the industry, one member specifically 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 joint venture's technology transfer efforts is that this independent supplier, not a participant in the joint venture, has also increased its yield of these boards.

2. International Competitiveness Issues

The health of the domestic PWB industry is fundamental to these companies becoming 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 PWB industry in the U.S. with its approximately 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, thus limiting the number of team members' responses relevant to each market segment, all members indicated that their companies' market share either stayed the same 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.

Most respondents expressed an opinion on how the PWB Research Joint Venture has affected the industry share in the different segments of the world PWB market. The responses indicate that the PWB project has increased industry's share in every market segment, with the strongest positive responses in the computer and military segments. No member was of the opinion that they or other members of the joint venture had increased their share at the expense of nonmembers, and 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.

Lastly, the members were read the goals of the ATP as stated in its enabling legislation. Albeit qualitative information, the members of the Steering Committee of this

Table 3. Summary of survey findings on partial early-stage economic impacts

Categories of Partial Early-Stage Economic Impacts	After 2 Years	At End of Project
Direct Impacts to Member Companies		
*Quantified Economic Impacts**		
Research Cost Savings		
Workyears 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

*These impacts are based only on those research tasks that the members thought they would eventually have done without the ATP, and not the cost and time savings associated with the new capabilities resulting from those tasks that they would not have done at all without the ATP.

joint venture generally agreed that the ATP had indeed fulfilled its stated goals in the case of the PWB Research Joint Venture.

Summary and Conclusion

ATPs funding of the PWB Research Joint Venture Project has thus far had a number of direct and indirect economic impacts. Of the direct impacts, the largest to date has been the increase in R&D efficiency. The project achieved at least a 53 percent reduction in overall research costs. The increase in research efficiency has 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 3. Therein, the categories of direct economic impacts to member companies are separated into those for which dollar values were obtained and those for which dollar values were not obtained, so-called quantified and non-quantified economic impacts.

The survey results described in the previous sections and summarized in Table 3 should be interpreted as only partial and preliminary estimates of project impacts. First, although ATP funding of the joint venture has led directly to research cost savings and early production cost savings and quality improvements, the bulk of the production cost savings and performance gains will be realized in the future both in member companies and in other companies in the industry as the research results diffuse and are more widely implemented. As such, the valued economic impacts reported in Table 3 are a conservative lower-bound estimate of the long-run economic benefits associated with ATP's

funding of the joint venture research.

In the methodology implemented thus far, data collection has focused on gathering from participants their best estimates of cost savings and economic benefits, relative to a counter-factual situation without the ATP. The participants in the PWB Research Joint Venture are obviously those in the most informed position to discuss research cost savings, potential applications, and economic consequences that they have realized from the results obtained. The methodology does not as yet include consideration of market-determined economic benefits deriving from the joint venture research. Full impacts across the marketplace cannot be observed instantaneously at the end of the project, but only in the future as research results diffuse and become embodied in PWB products.

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Author Biography

Albert Link is Professor of Economics at the University of North Carolina at Greensboro and co-editor of the *Journal of Technology Transfer.*

Estimating Economic Impacts of New Dimensional Control Technology Applied to Automobile Body Manufacturing*

CONSAD Research Corporation

Pittsburgh, PA 15206

Abstract

CONSAD analysts investigated the effects of the ATP-sponsored project on controlling dimensional variation in manufacturing (the "2mm project"). They looked first at the firm level to determine the technological changes that resulted from the project; the role played by the ATP; and the direct impacts on automobile production and maintenance costs. They then used macroeconomic interindustry modeling to project preliminary impacts on the national economy of adoption of the technology by the automobile industry. A challenge was to estimate the impacts based on preliminary and partial information characterizing industry experience. Some potential effects of the ATP-sponsored project were considered too uncertain at this early stage to attempt quantification and were omitted from the analysis. The results of the macroeconomic analysis provide a very preliminary projection of national economic impacts of this ATP-sponsored project.

Introduction

One of the early research joint-venture projects that was awarded funding by the Advanced Technology Program (ATP) was the "Development of Advanced Technologies and Systems for Controlling Dimensional Variation In Automobile Body Manufacturing" ("The 2mm Project"). The ATP award was made in 1991. The research began in September of 1992, and was completed in January of 1996. A total of $4.860 million in funding was committed by ATP, and an additional $9.007 million in funding was committed by the joint venture. The joint venture was comprised of: (1) a group of small- and medium-sized companies that supply assembly line equipment and consulting engineering services to automobile manufacturers and together form the Auto Body Consortium (ABC), consisting at the start of the project of eight members: APX International; ASC, Incorporated; Classic Design, Inc.; Detroit Center Tool, Inc.; ISI Automation Products Group; Modern Engineering; Perceptron, Inc.; and Progressive Tool & Industries Company (PICO); (2) the University of Michigan; (3) Chrysler Motors Corporation, General Motors Corporation (GM); and (4) Wayne State University as a subcontractor.

The 2mm Project developed technologies to control dimensional variation in automobile bodies during assembly. At an "ideal" automobile assembly plant, the sizes of openings, surfaces, parts and subassemblies would be identical on each assembled automobile body. In a real assembly plant, these sizes differ from automobile body to automobile body. These differences in sizes are referred to as dimensional variation. In addition to their application in automobile assembly, the technologies and processes that were developed as part of the 2mm Project have potential application in other industries that manufacture products which require the automated assembly of metal parts such as the appliance and metal furniture industries.

This paper summarizes the results of a study of the 2mm Project carried out by CONSAD Research Corporation under contract to the National Institute of Standards and Technology. First, the project is described as well as the problem it addressed. Then the role played by ATP is assessed. Results of early implementation of project technologies are used to estimate longer-term impacts.

Project Goals

The three stated goals of the 2mm Project were: (1) to achieve no more than a 2.0 mm variation for body-in-white (BIW) build, (2) to advance the understanding of the physical properties of sheet metal and the assembly of sheet metal parts, and (3) to enable the companies to perform the improvements on their own. The BIW is composed of the underbody, side frames, roof, shelves and backpanel. The door, hood, and deck-lid panels are installed into the openings of the assembled BIW. Later, after painting, the windshield and backlight are installed into the appropriate openings. If the BIW openings, panels, or other subassemblies vary significantly from their specified dimensional values, the assembly process can become more complicated and time-consuming than ordinary. In some cases, a BIW may require custom manual work to allow the parts to be assembled properly. In addition, the overall fit and finish of the completed automobile may be compromised if the dimensional variation is large. If the dimensional variation of a BIW is so large that it cannot be assembled properly,

* This paper is based on a study performed by CONSAD Research Corporation of a project funded by the Advanced Technology Program.

it may be removed from the assembly line and discarded.

Although some dimensional variation will always occur during automobile assembly, a goal of the automobile manufacturers is to design an assembly line system that accounts for the intrinsic variation in parts, subassemblies, and materials in a way that minimizes the total dimensional variation of the finished automobile body. The 2mm Project addressed the subject with expertise and experience from both industry and academia. The goal of the 2mm Project was to reduce the standard measure of total dimensional variation for assembly plants that adopt the project's technologies to 2.0 mm or below.

Automobiles produced by Japanese companies are generally perceived by the public to have higher quality than American cars. A report by J.D. Powers placed eight automobile models produced by Japanese manufacturers among the ten best automobiles ranked in terms of initial quality and customer satisfaction (Power and Associates 1995). Most Japanese manufacturers currently operate their U.S. and foreign assembly plants at or below 2.0 mm of total dimensional variation. Automobile industry experts believe that the U.S. market share of U.S.-made automobiles would increase if their perceived quality were to match or exceed that of Japanese cars. The 2mm joint-venture project was the response of U.S. manufacturers and suppliers to develop a coordinated and feasible approach in conjunction with assembly plant workers to solve the dimensional control problem.

Research Tasks

The 2mm Project research tasks were grouped into four program areas. These areas were dimensional measurement technology, process control methodology, technology base for future body assembly systems, and technology transfer programs. The research tasks were conducted concurrently. Considerable communication of results occurred among the researchers performing the various tasks. Each task contained at least one representative from industry who led the effort, and at least one university faculty member. Other industry engineers and graduate students were involved in the research being performed. The research was performed at university laboratories, development occurred at facilities of the assembly line producers, and data were collected and results were implemented at the assembly plants. An overview of the four program areas, the research tasks, and the organizations involved in each task appears in Figure 1.

The Role of ATP in the 2mm Project Joint Venture

It appears unlikely that (1) this complex joint venture would have been formed and (2) funding for the research project would have been coordinated without direct administrative and financial involvement by the federal government. There are several reasons.

One reason is that the problem addressed by the 2mm project was a systems problem, requiring a high degree of coordination among a number of quite different organizations. The problem at issue could not be solved by these individual organizations acting alone, even if they strongly wished to solve the problem and were willing each to undertake a research task in their respective areas of expertise. Forming large, complex research joint ventures to address a systems problem is, however, a daunting effort. Many obstacles must be overcome to organize and carry out a multitask, interdisciplinary, integrated research effort across multiple organizations with differing missions, structures, and cultures. The ATP provided the impetus for the companies to overcome the coordination barriers and to come together to organize the research joint venture needed for the systems approach to solving the problem.

Another reason that ATP's role was likely critical is that as a direct result of the long history of stringent antitrust enforcement in the automobile industry, engineers employed by any U.S. automobile manufacturer are wary about cooperating or even communicating with their counterparts in the other domestic automobile companies. In this distrustful environment, explicit involvement by the federal government may be essential to securing the participation of domestic automobile manufacturers in any collaborative research effort, particularly in complex, multitask, multicompany efforts.

An additional factor that made ATP's role critical is that the companies that supply assembly line equipment and design services to automobile manufacturers are, in general, small- and medium-sized companies with limited access to financial capital. They typically do not have research budgets that are large enough that they can independently fund the types of tasks that were conducted in the 2mm Project, and automobile manufacturers are generally reluctant to fund research projects performed by their suppliers. Project provisions for sharing and disseminating research results further encouraged the members to cooperate in the formation of the joint venture.

Yet another major factor underlying ATP's role was that the risks were not shared equally by the different members of the joint venture. The primary bearers of the risk of incomplete success on the individual tasks were the specific assembly line producers that were directly involved in the tasks. To induce their participation in the 2mm Project, partial subsidization of their research activities was necessary to compensate them for bearing disproportionate risk. ATP's financial participation in the project helped members bring in university participation, decreased the financial outlay made by these companies, and, hence, the net risk that was borne by individual members of the joint venture.

Figure 1. Summary of tasks in the 2mm project

Program Area	Stamping (Die)	Tooling	Assembly (BIW: Body in White)
Dimensional Measurement Technology	Task 3: Measurement, Modeling, and Real-Time Numerically Controlled (NC) Path Generation for Free Form Surfaces Participants: f M	Task 2: Visibility Analysis and Sequencing Simulation for Tooling Certification Participants: d h M	Task 1: Computer Aided Design and Automated Setup for In-Line Optical Coordinate Measuring Machines (OCMM) Participants: g M
Process Control Methodology	Task 4: On-Site Measurement and Process Monitoring for Stamping Participants: C M	Task 5: Information Feedback for Tooling and Process Design Participants: c1 h C M	Task 6: Process Navigators for Automobile Body Assembly Participants: c M
Body Assembly Technology		Task 8: Optimal Non-Rigid Sheet Metal Part Holding Participants: a M	Task 7: Variability Characterization and Tolerance Budget Analysis for Body Manufacturing Participants: C2 G M
		Task 9: Robust Design of Work-Holding Fixtures Participants: a1 e M	Task 10: Optimization in Multiple Panel Fitting Participants: b M
Technology Transfer			Task 11: Technology Transfer Participants: a C G W

Key to Participants

Auto Body Consortium:
- a APX International
- b ASC Incorporated
- c Classic Design, Inc.
- d Detroit Center Tool (DCT)
- e ISI Automation Products Group
- f Modern Engineering
- g Perceptron
- h Progressive Tool & Industries, Inc. (PICO)

Auto Makers:
- C Chrysler Motors Corporation
- G General Motors Corporation

Universities:
- M University of Michigan
- W Wayne State University

Implementation of 2mm Project Results by Joint Venture Members

Portions of the technologies and methodologies developed under the 2mm Project already had been transferred into operation at five motor vehicle assembly plants at the time of the case study: namely, Chrysler's Jefferson North assembly plant in Michigan; GM's Cadillac assembly plant at Hamtramck, Michigan; and GM's truck assembly plants at Shreveport, Louisiana; Moraine, Ohio; and Linden, New Jersey. Each of them was reported to have realized or exceeded the 2.0 mm goal. Since the study was conducted, a number of additional motor vehicle assembly plants have adopted the technology. Adoption by other industries is possible in the future but had not yet occurred at the time this paper was prepared.

Estimating the Economic Impacts of the 2mm Project

Initial estimates of economic impacts were made based on expert judgments of the expected future changes in costs and final demand that will result from adoption in automobile assembly plants. These judgments were obtained by CONSAD researchers from manufacturing engineers involved with the 2mm Project's research tasks, from industry and trade experts, from market analysts, and from economists with experience in the automobile and discrete manufacturing industries. The individual sources of information and judgments and information from individual plants and firms adopting the technologies are not cited because of the proprietary and confidential nature of the data. Other factors that could affect cost or demand are assumed to have remained constant.

Separate estimates are developed for the economic impacts of cost reductions resulting from productivity improvements and the economic impacts of demand increases. Different approaches were taken because it was CONSAD's view that attempts to estimate within the context of the macroeconomic model the effects of decreases in expected costs of the magnitude projected for the automobile industry, although sizable, would be infeasible. This is because the changes are likely too small in relation to total U.S. economic activity to have a reasonable expectation of being isolated and hence measured. In contrast, it was CONSAD's view that it *was* feasible within the scope and budget of the project to allow assessment of the project's quality improvement impacts in relation to total U.S. economic activity.

Estimated economic impacts of the expected reduction in production and maintenance costs are measured in terms of the total savings that might be realized by the automobile manufacturers. The cost reductions comprise substantial cost savings for the manufacturers, some unestimated portion of which may be shared with customers. The cost savings provide manufacturers with increased flexibility in applying pricing strategies that influence their market shares and profits. Equivalently, the cost decreases provide the automobile manufacturer with the option of adding more features to cars without increasing price. Allocating the cost savings between producer and consumer was not attempted.

The estimated economic impacts of the increases in market demand that are expected to be stimulated by improvements in product quality are measured in terms of the changes in total industry output and total private employment that are projected to result from those demand increases, other factors being constant. A macroeconomic model is used to estimate the economic impacts from increased market demand.

Implementation of the technologies developed by the 2mm Project will also substantially decrease the time required to launch the assembly of new automobile models. Industry experts assert that the reduction in launch times will generate sizable increases in sales for automobile manufacturers' popular new models. The available information was insufficient, however, for reliable estimation of the magnitude of the dollar sales increases, and this effect was omitted from dollar estimates.

Because the technologies developed by the 2mm Project are new, at the time of the study their impacts on industrial production and economic activity were not yet revealed in the extant empirical data on industrial performance. Therefore, to obtain realistic estimates of the likely magnitudes of any of the impacts, judgments about the anticipated consequences of applying the technologies had to be elicited from two groups of experts.

First, experts knowledgeable about the substance of the technologies were interviewed to obtain their judgments about how practical application of the technologies would affect the production processes (e.g., the utilization rates of specific inputs and the resulting production costs) and the quality of products in firms that adopt the technologies. The experts who were interviewed in this regard consisted primarily of university researchers and manufacturing engineers who were directly involved in research tasks performed on the 2mm Project, and technicians and engineers who were involved with the initial implementation of project results at the first-adopting five automobile assembly plants.

Second, experts knowledgeable about the industries and markets in which the technologies would likely be used were interviewed to obtain their judgments about the expected extent and rate of adoption of the technologies in those industries and markets. The experts who were contacted for this purpose include industry and trade experts, market analysts, and economists who have experience relating to the motor vehicle and discrete manufacturing industries.

The plausibility of the judgments provided by the two groups of experts was then evaluated by examining the coherence among the judgments provided by the various experts in each group. In addition, to the degree possible, the judgments were compared to the available empirical data on the outcomes of the initial applications of the technologies in actual industrial situations (i.e., in motor vehicle assembly plants where the technologies had been implemented), and to published evidence on the outcomes of applying similar technologies in comparable circumstances.

The macroeconomic interindustry model that was used in the study to estimate the impacts on the U.S. economy of increased demand from quality improvements was the Regional Economic Models, Inc., (REMI) Economic and Demographic Forecasting and Simulation 53-Sector (EDFS-53) Model of the national economy (for further description of the REMI model, see Treyz 1993). The model contains numerous structural equations that describe: production and output; population and the supply of labor; demands for labor and capital (including residen-

tial structures, nonresidential structures, and equipment); and wages, prices and profits. Interindustry transactions are represented by an input-output structure based on the input-output tables compiled by the Bureau of Economic Analysis (BEA). Equations representing behavioral relationships based on economic theory endogenously determine feedbacks on final demands among different industries in the economy. The model also characterizes substitution among inputs in response to changes in their relative costs, and wage adjustments in response to changes in labor market conditions. The version of REMI model that was used in the study forecasts economic activity for 53 economic sectors (including 49 private nonfarm industries, three government sectors, and the farm sector) and the aggregate national economy.

Estimated Benefits of Automotive Production Cost Savings

Engineers at GM's truck assembly plant in Linden, New Jersey, and 2mm Project researchers involved with the technology transfer at Chrysler's Jefferson North assembly plant estimate that net production costs—that is, production costs per car less the costs per car of implementing the 2mm technology—at those facilities have been reduced by approximately $10 to $25 per vehicle as a direct consequence of implementing results from the 2mm Project. The production cost savings are expected to vary at each assembly plant according to the current level of total BIW dimensional variation. The savings represent approximately one-sixth of one percent of the total production costs for an "average" automobile produced in the U.S. The reduction in production costs begins once the key technological components are in place and the automobile manufacturers' manufacturing engineers and line operators have adopted the 2mm Project's methodology. The production cost savings result from improved labor productivity and reduced waste during the assembly process.

The price of automobiles is highly inelastic with respect to changes in production costs. The automobile industry consists of a relatively small number of firms that produce highly differentiated products. When devising pricing strategies, automobile manufacturers take into account the anticipated responses of their competitors (Fellner 1972). They also use short-term pricing tactics that include factory rebates and temporary product sales to compete for customers based on price. It is, therefore, unlikely that the projected decrease in production costs will directly stimulate a discernible reduction in the price of automobiles. However, since the market for automobiles is very competitive, the results of the 2mm Project will allow the automobile manufacturers who adopt the dimensional variation technologies to be more flexible in responding to changes in the market for automobiles.

Industry experts estimated that, over the next five years, all of GM's and Chrysler's assembly plants would adopt the results of the 2mm Project. Upon full adoption, an estimated $10 to $25 net savings realized on each of the approximately 6.5 million cars and light trucks produced annually by GM and Chrysler will amount to an overall net savings of approximately $65 million to $160 million annually. To the degree that the price of automobiles does not decline in response to the projected decrease in production costs, the automobile manufacturers will realize increased profits.

Estimated Benefits of Automotive Maintenance Cost Savings

While an automobile is under warranty, the automobile manufacturer compensates the automobile dealer who performs repairs on the automobile. According to representatives of GM and Chrysler, approximately $500 of the retail price of a new automobile, on average, is associated with the expected amount of maintenance work that will need to be performed while the automobile is covered by the manufacturer's warranty. Only a portion of this maintenance work is necessitated by the quality of the BIW; the rest involves repairs to other components, such as the powertrain, the electrical and computer systems, and interior and exterior trim. Maintenance costs vary among automobile models. No data currently are available to characterize how much maintenance work will be avoided in the future due to the reduction in dimensional variation of BIWs that will result from the implementation of 2mm Project results. The magnitude of the cost savings associated with avoiding future maintenance work is clearly lower than the hypothetical limit of approximately $500 per vehicle, but is not known at this time.

Precise estimates may be possible in the future, as automobiles that are assembled using technologies developed by the 2mm Project complete their warranty period. At present, however, estimates of the reduction in maintenance costs that will be achieved for automobiles are necessarily imprecise. The average decrease is estimated to lie in the range of $50 to $100 per vehicle.

If, as industry experts anticipate, the project's results are adopted in all of GM's and Chrysler's assembly plants within five years, maintenance cost savings will ultimately be realized on all of the approximately 6.5 million cars and light trucks produced in those plants annually. Thus, over the useful lives of the vehicles produced in those assembly plants during a year, total savings in maintenance costs ranging from $325 million to $650 million are estimated as a result of the 2mm Project. If sales of vehicles assembled in the plants remain relatively stable over time, this level of total cost savings becomes the estimated annual cost savings, on average, over time. Much of the savings will accrue to the automobile manufacturers during the vehicles' warranty periods; the balance will accrue to the vehicles' owners thereafter.

Estimated Macroeconomic Impacts of Automobile Quality Improvements

The largest impact of the 2mm Project anticipated by the joint venture members is an increase in market share for U.S.-made automobiles due to improved product quality. Currently, industry experts believe that, on balance, the styling, performance, and price of automobiles manufactured by U.S. companies are comparable to those of automobiles produced by foreign companies. However, the quality of American automobiles, measured through customer surveys (e.g., Powers and Associates 1995), is perceived to be less than that of foreign-made automobiles.

Figures 2 and 3 present estimates of the increases in total industrial output and total private employment in the U.S. that are expected to be stimulated by the quality improvements achieved by U.S. automobile manufacturers through their adoption of "2mm" technologies. Although substantial economic impacts are associated with the direct effects of the 2mm Project on the automobile manufacturers, even larger estimated impacts are expected to be realized by the entire U.S. economy because of the larger indirect effect that a change in sales in the automobile industry will have on many other business sectors. These economic impacts were estimated in simulations performed using the national economic model. Underlying the estimates are judgments by joint venture members and other automobile industry experts about the increase in market share that will be elicited by the improvements in automobile quality.

Only the lower-bound scenario has been simulated. The scenario analysis assumes that the total size of the market for automobiles will not be affected by the project, but that the percentage of total U.S. automobile sales captured by GM and Chrysler will be higher at the expense of foreign-made automobiles. The lower-bound scenario assumes that the combined market share of GM and Chrysler will increase (relative to the baseline) by 1.0 percent. The value represents the smallest estimate obtained by CONSAD from industry experts.

Projections of the impact of the expected change in product quality on sales of U.S. produced automobiles were developed by estimating the increase in sales of domestically produced automobiles that would result from an increase in market share for GM and Chrysler. For a given level of increase in market share for GM and Chrysler, the change in sales of domestically produced automobiles is estimated to be equal to the increase in market share for GM and Chrysler multiplied by the ratio of the current market share for imported automobiles to the total U.S. market share for automobiles NOT produced by GM or Chrysler. This approach is based on the assumption that increased market share for GM and Chrysler that displaces the sales of imported automobiles will result in an increase in economic activity in the U.S. In contrast, it is assumed that increased market share for GM and Chrysler that displaces domestically produced automobiles will have no net effect on economic activity in the U.S. It is further assumed that Ford's market share will remain constant during the period of analysis. This assumption seems conservative given that all the U.S. assemblers share the same supplier base.

The projected increase in market share was introduced as an input into the REMI model, and the corresponding future changes in industrial output and private sector employment were estimated by the model. Estimates are presented for the years 1995 to 2000. Impact estimates for years after 2000 are not reported because of the increasing uncertainty in predicting developments in automobile production technology farther into the future.

Figure 2 shows that the quality improvements of the 2mm technologies in the automobile industry are projected to stimulate an increase in total industrial output in the year 2000 of more than $3 billion. The cumulative output increase between 1995 and 2000 is projected in excess of $8 billion, based on the lower end of the range of assumed market share response.

The REMI model was also used to project how the quality gains might affect employment. As shown in Figure 3, quality improvements in automobiles may stimulate thousands of new jobs across the economy, taking into account interindustry effects and assuming that the economy is able to absorb new jobs. The REMI estimates are based on the assumption of a Keynesian economic response to the modeled changes in product quality which permits an increase in employment to occur without the assumption of an immediate constricting action in monetary policy to offset the employment gains. Of course, to the extent that the economy is operating at full employment with strong wage pressures over this period, there would be a tendency for newly created jobs to be filled by workers moving from existing jobs, a tightening in monetary policy, and less opportunity for a net gain in total national employment.

Limitations

The methodology used for this case-study analysis relied on expert judgments and limited data to characterize and estimate the economic impacts of the technologies developed by the 2mm Project, and implemented by automobile manufacturers. The use of experts was necessary because of the lack of extant empirical data describing: the direct impacts of the 2mm Project technologies on the production processes across different assembly plants (estimates were based on the experience of several plants); the rate of adoption of the technologies by automobile manufacturers; and the magnitude of impact of the resulting increase in product quality on the sales of automobiles. These data had to be estimated because the new technologies developed by the 2mm Project are in the early stages of adoption at automobile assembly plants in the U.S.

The use of judgments from experts who are familiar with the technologies developed as part of the 2mm Project

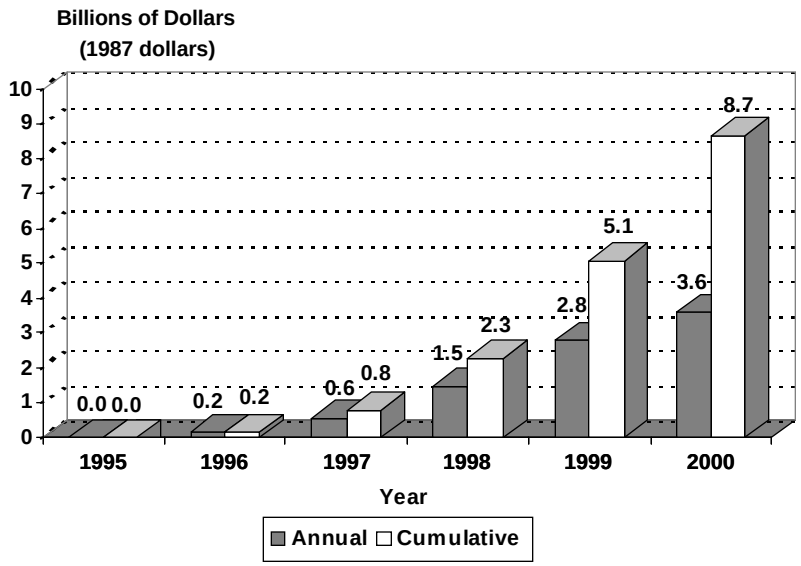

Figure 2. Estimated increase in total industrial output due to the adoption of 2mm program results by automobile industry based on assumed 1.0 percent increase in market share

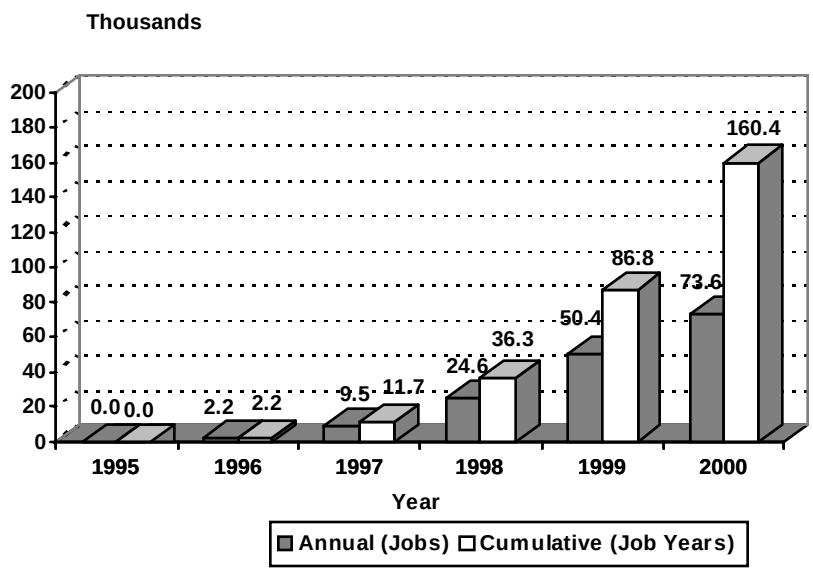

Figure 3. Estimated increase in total private employment due to the adoption of 2mm program results by automobile industry based on assumed 1.0 percent increase in market share

may result in biases but the existence, type, and size of possible bias cannot be determined at this time. Economic projections, in general, involve estimates of how individuals and firms will behave in the future under circumstances that may not be well-characterized by existing available data. Thus, all such projections rely on expert judgment to some extent. When more facilities have adopted the technologies, then additional data can be collected and compared with the expert judgment to gauge the accuracy of the estimates used in this analysis.

An additional obstacle to performing case studies such as this is the need for data which is sometimes viewed as proprietary by the companies. Since the existing data and information describing the specific impacts of the technologies developed as part of the 2mm Project pertain to specific company facilities that have already adopted part of the technologies, these data were considered proprietary in nature, to be treated as commercial secrets. Thus, the full details of the data used in estimating cost savings and market share have not been documented here, but have been used to guide the estimates and choice of parameter values used in the analysis. This situation is not uncommon in performing industrial case studies, and will probably not be addressed differently in other case study analyses since it is the nature of firms in competition to maintain certain information as proprietary.

A further limitation was that not all of the observed effects of the technology on the automobile industry could be modeled using the REMI model. For this case-study analysis, although the estimated auto production cost changes associated with the adoption of the technologies are sizable, these costs are relatively small compared to the total production costs of the automobile manufacturing industry. The analytic content of the 53-sector REMI model was not detailed enough to allow projecting of the total impact of the production cost savings on the entire economy. But production and maintenance cost savings were modeled and estimated outside the REMI model. Finally potential impacts from adoption of the technologies by other manufacturing sectors were omitted. At this early stage, there is simply too little information on the likely adoption of the technologies by other manufacturing sectors and the resulting impacts on production costs, product quality, and sales in those other sectors.

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Key Concepts in Evaluating Outcomes of ATP Funding of Medical Technologies

Andrew J. Wang
Advanced Technology Program, National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Gaithersburg, MD 20899

Abstract

The Economic Assessment Office (EAO) of the Advanced Technology Program (ATP) commissions economic studies by outside research organizations. A recent study by the Research Triangle Institute (RTI) outlines a framework for evaluating ATP funding of medical technologies. The RTI study employs a standard approach to cost-benefit analysis, while utilizing a number of methods unique to health care assessment to measure the benefits brought about by the new medical technologies. This article highlights important analytical points and explicates key concepts forming the basis of understanding for the approach. Concepts of economic returns, such as private and social returns, and the returns to public investment, are discussed in the framework of cost-benefit analysis and net present value. For analyzing the benefits of new medical technology, methods from health care assessment and concepts such as QALYs and the statistical value of life are identified and explained.

Introduction

As part of its effort at economic evaluation and research, the Economic Assessment Office (EAO) of the Advanced Technology Program (ATP) commissions economic studies conducted by outside research organizations and economists. One recent study, completed by the Center for Economic Research at the Research Triangle Institute (RTI), is described in the research report *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies* (RTI 1998). This report concludes an evaluation effort conducted by RTI for EAO, focusing on a set of ATP-funded projects in the developing medical technology field of tissue engineering.

The RTI study examined a set of seven ATP projects in tissue engineering with an aim to developing and demonstrating an evaluative framework that would enable the estimation of economic benefits from ATP funding of new medical technologies. In general terms, the overall framework of analysis can be considered to be cost-benefit analysis. But beyond the general framework, the substantive issue of interest is what are the details and specifics of how the costs and benefits are estimated and analyzed, and what is the framework for estimating and analyzing costs and benefits associated with an investment. For evaluating the impact of new medical technologies, the key question is how to evaluate health benefits to patients that are brought about by medical innovation.

This article will outline the general methodology taken in the RTI study, and will highlight and explicate the most important conceptual points critical to a proper understanding of the methodology. Section II defines and clarifies concepts of economic returns. Section III identifies social benefits from new technologies and explains how public investment may affect overall returns. Section IV explains the key concepts of quality-adjusted life year (QALY) and "value of life" that are central to the evaluation of benefits associated with new health care or medical technologies. Section V provides a brief conclusion.

Concepts of Economic Returns

Net Present Value

The correct measure of the economic value of an investment that produces a stream of benefits is the *net present value*. Net present value (NPV) is defined as the "discounted" present value of all net benefits associated with an investment project. Net benefits NB_t in any time period t is total benefits minus total costs in time period t. Net benefits that occur in later periods are "discounted" to make them comparable with net benefits in the present. The net present value of an investment project is then defined as the sum over all time periods of discounted net benefits.

The rationale for discounting net benefits that occur in the future is straightforward. A dollar today is not the same as a dollar tomorrow. A dollar today can be invested at a rate of return r, and is therefore worth (1+r) dollars tomorrow. More generally, a dollar in the present, invested at a rate of return of r per period, is equivalent to $(1+r)^t$ in a future period t. Similarly, a dollar in a future period t is equivalent to $1/(1+r)^t$ dollars in the present period, and so the discounted value, or present value, of net benefit NB_t occurring in time period t is equal to $NB_t/(1+r)^t$.

Net present value can be expressed as

$$\text{(1)} \qquad NPV = \sum_{t=0}^{T} \frac{NB_t}{(1+r)^t},$$

where NB_t is net benefits in period t, and r is the discount rate. The discount rate r is specified to be the currently prevailing rate at which dollars today are traded for dollars tomorrow—it is the intertemporal price for dollars traded between time periods, which is the "opportunity cost" for funds available for either investment or consumption. Equation (1) shows that costs and benefits in all periods are first translated into net present value terms, using the discount rate r, and then the separate net benefit terms are summed to give the value of the project.

It is important to note that the NPV calculation already accounts for the best alternative use of funds by discounting net benefits at discount rate r. Thus, any project with an NPV>0, by definition, has economic value greater than prevailing economic opportunities. In other words, if NPV = $x is greater than zero, then the project is worth $x more than existing economic opportunities. The key point here is that a project with an NPV>0 is better than existing economic opportunities and is therefore worth doing.

Private Returns and Social Returns

Consider a private-sector investment decision. In calculating the NPV of an investment project, the investor will only take into account costs incurred by the investor and benefits that accrue to the investor. For a business company, these would be company costs and revenues associated with an investment project. This NPV calculation gives the private value of the investment to the private investor—it is the *private return* for the investment.

But when a private investor undertakes an investment, costs may be imposed on others as well, and benefits may also accrue to others. Consequences to others (i.e., costs and benefits), resulting from a given private action, are called externalities, or spillover effects. An NPV calculation that takes into account costs and benefits not only to the investor, but also to all others affected, gives the social value of the investment—it is the *social return* for the investment. The calculation for social return includes not only private costs and benefits to the private investor, but also all positive and negative externalities that affect others in society. Net benefits in the calculation of social return therefore includes "private" net benefits as a component of "social" net benefits.

Incremental Social Return on Public Investment

The social value of a given public-sector investment can be derived from a comparison of scenarios with and without the public investment. For concreteness, take the ATP to be the public investment program under consideration. Without ATP, some level of R&D investment is undertaken by the private sector, and the net present value of social benefits and social costs defines the social return associated with the private investment. With ATP, a different level of R&D investment may be undertaken by the private and public sectors together, and the net present value of all social benefits and costs (including the public investment costs) defines the social return associated with the combined private and public investment.

Figure 1. Social and private returns with and without ATP

	Social Returns	Private Returns
With ATP	A	B
Without ATP	C	D

In each time period t, incremental social net benefit can be defined to be the difference between social net benefit with ATP and social net benefit without ATP. The net present value of this stream of incremental social net benefits defines the "incremental social return on public investment." Figure 1 shows that social return and private return can each be defined for a with-ATP scenario and a without-ATP scenario. The incremental social return on public investment is based on a comparison between social return with ATP and social return without ATP, that is, a comparison between cell A and cell C in Figure 1.

Social Returns and the Impact of ATP

Social Returns from New Technologies

As discussed above, social returns from investment can differ from private returns because of externalities, or spillover effects. Three classes of spillovers have previously been identified to ATP as relevant for evaluating the social benefits of new technologies (Jaffe 1996). First, there are market spillovers, which are benefits consumers receive that are greater than what they pay for, what economists call "consumer surplus." A consumer purchasing a good usually places a higher value on the item than the price paid—this excess of benefit or value over price is consumer surplus and is a market spillover benefit to the consumer. Second, there are knowledge spillovers, or benefits to other firms doing R&D that are able to learn from the R&D and innovation of a given firm. Third, there are network spillovers, or benefits to firms or consumers that stem from complementarities or interaction effects that may characterize a set of related technologies.

In the RTI study, the main focus in the estimation of social net benefits is the measurement of health benefits resulting from the application of new medical technologies. For the most part, these health benefits to individuals can be categorized as market spillovers to consumers. The RTI effort does not attempt to measure social benefits from knowledge spillovers or network spillovers.

Estimating Net Benefits of New Medical Technologies

Net benefits of new medical technology innovation may be disaggregated for analytical purposes into net benefits occurring in the health care delivery sector, and net benefits occurring in the medical technology sector. For the health care delivery sector, RTI's estimation of net benefits of new medical technology incorporates a measure of the value of health benefits to patients brought about by the medical innovation, and an estimate of changes in the costs of medical treatment due to the new technology. For the medical technology sector, net benefits include revenues resulting from sales of new medical technology products, less all investment and production costs associated with bringing the new technology to market (e.g., R&D investment, physical capital investment, commercialization costs, actual production costs).

In short, net benefit in the health care delivery sector is consumer surplus benefit to individuals—the value of increased health benefits to patients, and the decrease in medical treatment costs. And net benefit in the medical technology sector is total revenues minus total costs, or total profits generated in this sector. More accurately, net benefit is equal to the change in total profits in the sector, after revenues and costs for the old displaced technologies are properly accounted for. Overall, total social net benefit is equal to the sum of consumer surplus benefit from the health care delivery sector, and the change in total profits from the medical technology sector.

The Impact of ATP on Social Returns

The rationale for a public investment program such as the ATP is that public investment can have a significant impact on social returns. As outlined above, the incremental social return on public investment is based on a comparison of social returns for scenarios with and without the particular public investment under consideration. For evaluating the impact of ATP investment, RTI identifies three ways in which ATP funding may increase social returns:

- Acceleration of R&D
- Increase in probability of R&D success
- Expansion of scope of R&D.

These three channels of possible ATP impact on the social return to R&D investment are discussed in turn—

1. ATP funding may accelerate R&D and thus lead to earlier introduction of the new technology. In the NPV calculation, more years of net benefits or earlier years of net benefits will tend to increase project NPV.
2. ATP funding may increase the intensity of R&D, which may lead to a higher probability of R&D success. When project success is uncertain, all net benefits for the project are expressed in terms of "expected value" in the NPV calculation. The expected value of net benefits for any given year is defined to be the probability that benefits will occur (i.e., the probability of project success), multiplied by the value of net benefits in the case of project success. Therefore, if ATP funding increases the probability of project success, the expected value of all net benefits will increase, and project NPV will tend to be higher.
3. ATP funding may broaden the scope of R&D to include a wider range of potential applications. With wider application of the technology, a greater number of patients will receive health benefits, and the increase in net benefits will tend to raise project NPV.

Valuing Health Benefits

Quality Adjusted Life Years (QALYs)

As discussed earlier, in estimating net benefits of medical technologies, a central focus is measuring the health benefits to patients. The concept of Quality Adjusted Life Year (QALY) was developed to make possible a quantification of health benefits to an individual in terms of the quantity and the quality of life (Torrance & Feeny 1989). The basic idea is that one year of life at less than full health can be considered equivalent to less than one year of life in full health. So a year of life in full health will be given a QALY value of 1.0, a year of life at less than full health will be given a QALY value between 0.0 and 1.0, and death will have a QALY value of 0.0.

Using QALY values assigned to health states, it is possible to quantify health improvements for an individual, as well as to aggregate health benefits across different individuals. A medical intervention that extends the life of person A by one year at an existing QALY level of 0.50, and produces a health improvement in person B equal to 0.25 QALY for one year, is considered to have produced 0.75 QALY in health benefits in total. Note that a 1 QALY gain to a young person is considered equivalent to a 1 QALY gain to an old person, and a gain of 0.50 QALY for one person is equivalent to gains of 0.25 QALY for two people. The concept of QALY is understood as a means to quantifying health outcomes, a method of accounting for years of life and quality of life in a single measure.

Where do QALYs come from? QALY values assigned to different health states are derived from surveys of individuals from a relevant population. Individual survey responses are personal subjective judgments on the quality of life in various health states. A population "average" response is taken to define the QALY values for health states. QALY values are therefore reflective of the population on which they are defined, and are not meant to be viewed as fundamental or immutable characteristics.

Various survey methods have been used to elicit QALY values from individuals. The "standard gamble" method is a conventional method often used that is considered to be

most theoretically consistent. Figure 2 illustrates the standard gamble method for eliciting the QALY value for a health state A. The individual surveyed is presented with a choice between Choice A (health state A with certainty), and Choice B (a lottery or gamble on full health with probability p and immediate death with probability 1–p). At some level of probability p, the individual surveyed will express indifference between Choice A and Choice B. That level of probability p defines the subjective QALY value for health state A, as expressed by the particular individual surveyed. As already mentioned, the QALY value for the population as a whole will be taken to be some average of the individual personal subjective QALY values. Table 1 shows QALY values for selected health states that have been reported in the health assessment literature.

Table 1. QALY values for selected health states

Health State	QALY Value
Full Health (Reference state)	1.00
Mild angina	0.90
Moderate angina	0.70
Home dialysis	0.64
Insulin-dependent diabetes	0.58
Rheumatoid arthritis	0.52
Severe angina	0.50
Blind, deaf, or dumb	0.39
Chronic obstructive pulmonary disease	0.38
Death (Reference state)	0.00

Source: RTI, 1998.

Value of Life, or the Pricing of Fatality Risk

Perhaps the most controversial, or most "controversial sounding," aspect of cost-benefit analysis is the idea of placing a value on life. As is often the case, what may seem to be controversial at first, turns out to be not so controversial, once ideas and language are clarified. In fact, in this case, the "value of life" is defined to be the value of a "statistical" life, which is itself just a measure of the observed price of fatality risks (Viscusi 1992).

The idea of the "statistical" life is based on the observation that a 1 in 100,000 risk of death to an individual is equivalent in statistical terms to 1 death in a society or community of 100,000 people. What the community is willing to pay collectively, to reduce deaths in the community by 1, is an appropriate measure of the value that society places on one life, or one "statistical" life. And what a community of 100,000 is willing to pay in aggregate, for a reduction in deaths by 1, is just equal to what a typical person in the community is willing to pay for a 1 in 100,000 reduction in the risk of individual death, multiplied by the number of people in the community, or 100,000. If, for example, each person in the community is willing to pay $50 for a 1 in 100,000 reduction in individual death risk, then the value of a statistical life in this community is $50 × 100,000 = $5 million.

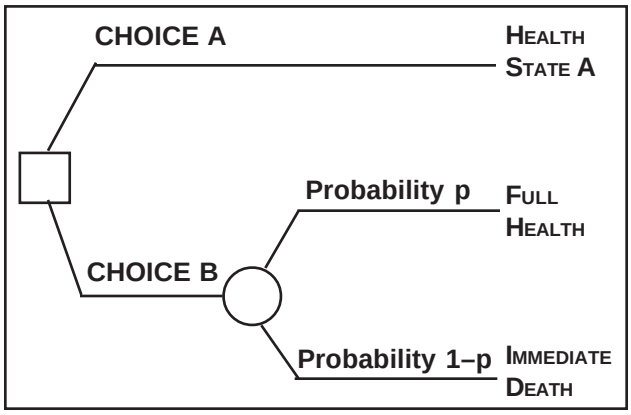

Figure 2. Standard gamble method of eliciting QALY value for a health state

The value of statistical life is then a reflection of individual willingness to pay for very small reductions in very small risks of death. A $5 million value of statistical life does not imply that an individual would be willing to accept certain death for $5 million, or a 0.50 increase in individual death risk for a payment of $2.5 million. For the same reason, the value of statistical life can be much greater than a person's total lifetime earnings potential. A person with total lifetime earnings well below $5 million may indeed be willing to pay $50 for a 1 in 100,000 reduction in death risk, implicitly valuing statistical life at $5 million.

Estimates of value of statistical life can be derived from observed data on the willingness to pay for reductions in fatality risks. Most of the empirical studies use labor market data to derive estimates of the wage premium (also known as the "compensating differential") associated with higher-risk jobs. The observed pricing of fatality risk in the labor market provides a good measure of the value of statistical life.

The empirical studies of the value of life based on labor market data place the value of life of workers in typical jobs in the range of $3 to $7 million. Like QALY values, the value of life must be properly understood as an "average" value for a given relevant population. For some classes of workers, the price on fatality risk, and consequently the implied value of life, is higher; for other groups of workers, the price of risk and the implied value of life will be lower. The purpose of using QALYs and estimates of value of life is to allow for a common basis of measurement. To the extent that QALY values and the estimated value of life are based on a population that is relevant to the analysis, the measurement function is served.

Monetary Value of QALYs

QALY values need to be converted to monetary terms for the purpose of analysis of net benefits and calculating economic returns. If the estimated value of life is taken to be $5 million, and this estimate is for an average worker at age 40 in full health with 36 years of remaining life expectancy, then the money value of a QALY might be calculated as $5 million ÷ 36 years = $139,000. But as explained earlier in the discussion of NPV, a dollar tomorrow is worth only 1/(1+r) today, and a dollar at time period t is worth only $1/(1+r)^t$ in the present, given the discount rate r. Thus, for 36 years of life in full health to be valued at $5 million today, the money value of each year of life must be equal to v defined by the equation

$$\$5\,\text{million} = \sum_{t=0}^{35} \frac{v}{(1+r)^t} . \tag{2}$$

Or rearranging, the money value of a QALY is given as

$$v = \$5\,\text{million} \Big/ \sum_{t=0}^{35} \frac{1}{(1+r)^t} . \tag{3}$$

For example, if the discount rate r is 0.03, then the money value of a QALY is v = $222,000.

Conclusion

In developing a framework for evaluating ATP funding of medical technologies, the RTI study employs a standard approach to cost-benefit analysis, while utilizing a number of methods unique to health care assessment to measure the benefits brought about by the new medical technologies. This article highlights important analytical points and explicates more fully key concepts that form the basis of understanding for the approach. Specifically, concepts of economic returns such as private and social returns, and returns to public investment, are discussed in the framework of cost-benefit analysis and net present value. And for analysis of benefits of new medical technology, methods from health care assessment and concepts such as QALYs and statistical value of life are identified and explained. Overall, the basic framework of evaluation presented by RTI in their study report is well grounded in established economics theory and is widely accepted in practice.

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Author Biography

Andrew Wang, an Economist in the Economic Assessment Office of the Advanced Technology Program, National Institute of Standards and Technology, holds a Ph.D. in Economics from Harvard University.

A New Lexicon and Framework for Analyzing the Internal Structures of the U.S. Advanced Technology Program and its Analogues Around the World*

Connie K. N. Chang
Advanced Technology Program, National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Gaithersburg, MD 20899

Abstract

Analogues of the U.S.'s Advanced Technology Program can be found in many countries around the world. These government programs provide financial assistance to firms and other entities to develop innovative technologies in the conviction that these developments will contribute to future economic strength. For political and economic reasons, these programs tend to be complex and intricate in their design. No informed evaluation and comparison of such programs can take place without a clear understanding of their internal structures. This paper analyzes the anatomy of such programs and constructs a vocabulary for understanding program design choices. It identifies and discusses a representative sample of important program design features—eligibility requirements, the nature of the research, technical scope, the selection process, and public-private financial arrangements—and provides examples of national programs embodying alternative design choices. This paper should interest policymakers, program administrators, program evaluators, and others involved in program design, management and evaluation.

Introduction

Analogues of the U.S.'s Advanced Technology Program (ATP) can be found in many countries of varying sizes and economic maturity around the world. These government programs provide financial assistance to firms and other entities for research to develop innovative technologies that underlie national economic growth. The technologies that are created with the help of such programs are expected to improve the competitive strength of organizations in terms of new capabilities and enhanced productivity, and lead to new products, processes, and services that will benefit the national economy and increase the number of high-wage jobs. These programs tend to be complex and intricate in their designs owing to the complex political and economic goals to be served. However, little attention has been given to understanding the internal structures and workings of such programs. Although a body of literature exists on comparing national civilian technology policies and strategies, not much work has been done on analyzing how particular programs operate or on comparing and contrasting the design of such programs. As a result, our understanding of these specific national programs and their comparative similarities and differences is limited. Without a lexicon with which to analyze and frame our understanding of these programs, our knowledge remains superficial and our comparisons faulty.

This paper attempts to help fill this knowledge void. It analyzes the anatomy of such programs and constructs a vocabulary for understanding program design choices. An informed debate about such programs can only take place when we have a firmer grasp of their internal structures. Others have noted the importance of examining program details. When speaking of ATP-like programs, Spender argues that "The program's details are vital given their intrinsically political judgments about the relationships between the public and private sectors, the fact that any government involvement in the private sector's markets needs justification, and that its design invites a clash of concepts about how innovation happens and a technologically-driven economy works" (Spender 1997, p. 51). Hill has also considered specific features of the ATP in regarding its design and opportunities for improving the program for greater success (Hill 1998).

This paper identifies and discusses a representative sample of important program design features—eligibility requirements, the nature of the research, technical scope, the selection process, and public-private financial arrangements—and provides examples of national programs embodying these design choices. When considering all programs, some have been in existence longer than others, providing opportunities for relatively young programs, like the ATP, to learn from the experience of older programs. Similarly, there are opportunities for older programs to examine how younger ones are designed for creative ways

*This paper is drawn from a draft report, "A Multi-Country, Binational Comparison of the ATP and its Analogues," by the author, prepared for the National Institute of Standards and Technology. The draft report covers additional program features of a number of programs in different countries.

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of doing things better. It is hoped that this new lexicon and framework of analysis will help us improve our understanding of how these programs operate. This paper should interest policymakers, program administrators, program evaluators, and others involved in program design, management and evaluation.

Building a Lexicon and Framework for Understanding Program Architecture

The following section identifies and discusses a representative sample of important program design features and provides examples of national programs embodying alternative design choices. Table 1 provides a summary view. (For a treatment of additional design features, see Chang 1998.) For each design feature, the ATP's approach is first described, followed by a discussion of how other programs have alternatively approached the same design feature.

Eligibility Requirements

Eligibility requirements are a primary constituent element of a program's architecture. The following questions help us examine this feature more carefully. Who is allowed to participate and what are the rules regarding that participation? Are only firms allowed to apply? Or, must firms pair with a university or non-profit organization? Who is allowed to be the lead organization in a project? Does the program require collaboration or are applicants left to decide? Answers to these questions reveal the design choices such programs have made, with respect to eligibility, and suggest concerns that underlie that decision.

The ATP requires for-profit firms to lead projects. Whether in a single-proposer project or a joint-venture project, firms are the lead organizations, with other companies, universities, non-profit organizations, and federal laboratories as their partners. This eligibility requirement reflects the prime program goal that the funded research will be followed by accelerated commercialization of new products and processes derived from the developed technology. By requiring projects to be industry-led, the ATP is deliberately designed to provide firms the incentive to pursue follow-on commercialization activities of project results with private sector funds. The rationale underlying ATP's focus on being industry-led is that economic benefits only result when the new technology is transitioned from the knowledge stage into new and better products, processes, and services for users (e.g., a new, improved medical treatment that is actually delivered to patients who then benefit from its use.)

At the same time, the ATP encourages participation by other kinds of organizations, including universities and government laboratories. The main objective of this aspect of eligibility is to strengthen the R&D effort and build the knowledge base. More than 125 universities are among the over 800 organizations (excluding subcontractors and informal partners) participating in the 352 projects funded by the ATP from 1990 through 1997. University participation is encouraged by requiring that projects press the state of the art. Many companies must turn to university research laboratories to extend their technical capabilities. Although the ATP does not force collaboration between firms or between firms and universities or non-profits, leaving the decision up to applicants in how best to structure their project, it has some built-in influences to encourage partnering. One incentive to partnering is provided by the rules governing financial assistance. By limiting the amount of financial assistance to $2 million for direct project costs for single-proposer projects (prior to 1998, companies regardless of size were required to cover their indirect costs only, but starting with 1998 awards, large companies may receive assistance for no more than 40% of total project costs—not to exceed $2 million, while non-large companies are only required to cover all of their indirect costs), the ATP encourages companies to partner in a formal way to solve larger problems. By capping the number of years of assistance to three years for single-proposer projects and five years for joint-venture projects, the ATP further encourages formal partnering to undertake longer-term projects. By setting stringent criteria for integration across technical and business project objectives, the ATP encourages companies to partner to meet the need for strength in multiple technical fields, markets, and knowledge diffusion. Joint-venture projects, defined by the participation of at least two, for-profit companies performing the research and sharing in the costs, are not limited by the amount of assistance provided, but more than half of the total project costs must be cost-shared by industry.

The LINK Scheme, an ATP counterpart program in the United Kingdom, began operations in 1988, the same year as ATP's authorizing legislation. LINK is aimed at enhancing the competitiveness of U.K. industry and the quality of life by supporting pre-competitive research in areas of strategic importance to the U.K. economy. In contrast to the ATP, LINK does not require firms to take the lead role. LINK requires project proposals to be a collaborative effort between firms and universities. One reason for this requirement is greater assurance that university ideas are taken up by U.K. industry and not by foreign firms, that is, the program promotes technology transfer out of the universities. Partners must come to an agreement on who will lead the project and in practice, project leadership is split 50-50 between universities and firms. By requiring firms and universities to work together, LINK program designers are not giving firms a stronger voice, but are intentionally encouraging proposed research projects to have equal relevance to both industrial and academic partners. LINK's design may increase the likelihood of technology transfer from universities to industry, and increase the diffusion of project results via academic publication. The question is whether the companies will be focused on rapid commercial progress.

Policymakers in other countries have made yet other

Table 1. Comparative features of the ATP and its analogues*

	U.S. Advanced Technology Program	Canada Technology Partnerships Canada (TPC)	E.U. Framework Program	Finland Tekes	Japan Teiankobo	U.K. LINK Scheme
Program Year of Launch	1988-Present	1996-Present	1984-present	1983-Present	1997-Present	1988-Present
Mission	Stimulate economic growth and accelerate the commercialization of technologies	Encourage economic growth and create jobs, specifically to help co's develop new products for export	Develop European S&T capability and meet other objectives	Stimulate economic growth	Creation of new industries	Enhance the competitiveness of U.K. industry and the quality of life
Technical Scope (open to all techs? pre-selected list? or hybrid?)	Hybrid General competitions are open to all; focused competitions fund specific tech areas. All techs must be high risk and enabling	Hybrid Pre-selected aerospace and defense; environmenta and enabling techs (open to techs that can create new industries)	Pre-selected list	Pre-selected list	Hybrid Energy and environment; and industrial S&T (open to techs that can create new industries)	Pre-selected list
Who Leads?	Industry	Either industry or university	Industry	Industry	Industry	Either industry or university
Nature of Research	Beyond basic science, prior to product development	Close to product development	Beyond basic science, prior to product development	Beyond basic science, prior to product development	Close to basic science	Mainly, prior to product development.
Formal or Informal Selection Process?	Formal	Formal	Formal	Formal	Formal	Formal
Cost-share Requirement	If single proposer, 100% of indirect costs (if large business, minimum 60% of total project costs). If joint venture, greater than 50% of total project costs	Typically 70-75% of total project costs	Minimum 50% for industry. 0% for university partners	Minimum 50% of total project costs	N.A.	Minimum 50% of total project costs

*This table is taken from a draft report by Chang, "A Multi-Country, Binational Comparison of the ATP and its Analogues," prepared for the National Institute of Standards and Technology and planned for publication in September 1998.

program design choices with respect to eligibility. For example, the European Union's Framework Program for Research and Technological Development which was launched in 1984 provides financial assistance for pre-competitive research to trans-European consortia. Each project must have a minimum of two independent partners based in two different member states. Projects that promote coordination or collaboration between member states are given greater consideration. The addition of a geographical element to the eligibility criteria reflects the program's political objective of creating a united European research community.

A program that is designed to allow only for-profit firms to apply as the lead organization, in either a single proposer project or a collaborative project, may be trying to ensure that the research being pursued is relevant to industry. Moreover, by placing a firm at the helm a program may be seeking more commitment from the proposing firm in bringing technologies developed during the project into commercialization. In contrast, a program that allows or encourages universities, research institutes, non-profit organizations, or government laboratories to be the lead applicant may perhaps reflect the belief of its architects that universities are as capable as firms in creating new technologies for the marketplace, or perhaps, it may reflect a greater interest in knowledge creation and less concern about future commitment to commercialize new technologies. It may have less concern about research results being exploited by firms in other countries instead of its own. A program that requires collaboration between firms and universities, or firms and national laboratories may do so with the goal of transferring knowledge created by universities or national laboratories to industry. They may be more focused on the diffusion of existing new technologies created in universities and national laboratories and less concerned with the particular interests of industry.

The Nature of the Research

The kind of research a program supports reveals the nature of the problems it is addressing. Along the research spectrum, a program may fund research that is closer to basic science (without attention to potential uses), or it may fund product development work (there may be serious barriers to bringing technologies to market), or it may fund somewhere in between these two ends of the continuum. It may fund applied research to develop enabling technologies with some anticipated applications as well as many potential uses not yet envisioned. It may focus on the research interest of a single firm or group of firms, or it may be more concerned about effects that will likely extend beyond the direct award recipients. It may focus on easy-to-assimilate, incremental technologies, or revolutionary technologies that entail radical changes for their users. Choices such as these reveal a balance by the program of public interests and private interests, of feasibility and risk, of deliberate goal seeking and unknown outcomes.

The ATP funds research that can lead to the creation and rapid commercialization of high-risk, enabling technologies that have the potential to generate economic and technical opportunities that can lead to broad-based benefits for the nation. The ATP does not pay for product development or other expenses related to commercialization; and it does not fund projects that are geared to creating new knowledge for knowledge's sake without an evident pathway to commercialization. It is designed to create innovative technologies which have the potential for widespread commercial application with benefits extending far beyond the direct award recipients.

Like the ATP, the U.K.'s LINK Scheme funds long-term, enabling and generic research to enable and accelerate the commercial exploitation of science and technology, leading to new products, processes, systems, and services. In contrast, Technology Partnerships Canada (TPC), a Canadian counterpart program to the ATP launched in 1996, funds nearer-to-market projects. The TPC program provides funding for activities related to the development and demonstration of products, processes, and technologies (including research, development, technology commercialization, sustaining technology, quality management, and technology integration and acquisition); pre-production to develop production capabilities; and studies related to potential projects or the identification and assessment of strategic technology opportunities.

Technical Scope

The technical scope of a program refers to the technologies that qualify. It takes the category of research discussed above as given (e.g., "pre-competitive," "enabling," "high-risk") and goes one step further in asking what technologies within this category of research are eligible for funding (i.e., within the program's scope). Among the possibilities are that a program provides funding to eligible organizations for research to develop technologies of their own choosing with little involvement of government. Another is that technologies/topic areas/themes are set in advance by legislators or program administrators. Hybrids of the two provide other options. For example, eligible applicants might have the option to propose project topics either in technology areas of their own choosing or in pre-selected areas. As another example, eligible applicants might propose whatever they like, but program administrators might screen them based on public-interest criteria.

The ATP takes a hybrid approach. It offers both general competitions which are open to all technologies, applications and ideas, and focused program competitions which fund interlocking sets of projects that are focused on achieving pre-specified technical and economic goals. Focused program ideas in the ATP are generated from industry input in the form of white papers and are further developed in public workshops and meetings held by

program managers. Only program ideas that best meet selection criteria that are designed to accomplish the program's mission—high technical challenges, broad-based economic benefits, industry commitment, and the necessity of ATP support—are selected as new programs. Project proposals for focused program competitions are evaluated against published selection criteria, as are project proposals submitted to general competitions. By concentrating funding in particular areas while allowing proposals that fall outside the technical scope of these areas to be submitted to general competitions, the ATP tries to ensure an open door to all excellent ideas, while concentrating its investment impact in certain areas which have the potential to deliver large national benefits. Examples of focused programs are photonics manufacturing, catalysis and biocatalysis technologies, tools for DNA diagnostics, tissue engineering, and adaptive learning systems.

Canada's TPC program focuses its funding on three main technology areas—aerospace and defense; environmental, and enabling technologies. Like the ATP, the TPC program employs a hybrid approach by pre-selecting three areas, the last of which offers firms the chance to propose research topics that are broader than the other two. This last area, enabling technologies, is open to proposals that can create new industries or show the potential to transform and strengthen the basis of competition in whole industry sectors, including proposals to develop advanced manufacturing and processing, advanced material processes and applications, biotechnology, and advanced information technologies.

In contrast to the U.S. and Canadian hybrid programs, the U.K.'s LINK Scheme favors pre-selected themes. LINK has 58 programs focused on particular technology or market areas that provide support for research of strategic importance to the U.K. economy. These programs are categorized under the main headings of food/agriculture, electronics/communications/IT, biosciences/medical, materials/chemicals, and energy/engineering. Each program typically receives financial support from a number of Government Departments and Research Councils. Since 1995, new LINK programs have been responsive to priorities identified under an initiative called Foresight which brings together industry, academia, and government to identify long-run trends in markets and technologies in the United Kingdom and emerging opportunities for U.K. industry, and to suggest possible courses of action to take to benefit from these opportunities.

Another example of a program taking the pre-selected approach is Finland's TEKES, or the Technology Development Center. It began operations in 1983 and aims to help firms develop technologies that can lead to internationally competitive products, production processes and services. At the beginning of the program, a committee was set up and proposed twelve nationally important areas to improve Finland's technological capabilities. Since then, further programs areas have been driven by industry. Technology areas are decided after workshops and conferences are held by TEKES to gather and develop ideas with industry. The program areas link firms in specific industrial sectors with the aim of raising their collective technological know-how. Program areas have included planning and manufacturing technology for electronics, computer-integrated manufacturing technology, construction technology, mining technology and pulp and paper technology.

A program that is open to all technologies may be more responsive to where industry wishes to go, and more flexible in responding to changes in the marketplace. It may be more able to invest its resources in areas that most need government assistance at the moment. A program that limits its funding to pre-selected technologies may be less flexible in responding to changes in the marketplace, but may benefit the nation by concentrating a critical mass of funding in specific technology areas that meet particular goals. In making its selection of technical areas, a program may consult with industry to identify areas that are important to them to help ensure that follow-on commercialization will occur. However, as Kelley points out, the disadvantage with this approach is two-fold: it "presupposes that the agency has the internal staff expertise to assess what it learns from these interchanges" and it "may tend to favor technical areas of interest to [well-established groups within the private sector R&D community that have a greater capability to engage in such dialogue with a government agency] over those proffered by new or less well-organized groups." (Kelly 1997, p. 323). A program that takes a hybrid approach in defining its scope of activity may be able to take advantage of the positive features of both while limiting the disadvantages of each.

The Selection Process

When considering programs in all countries, selection processes by which projects are chosen for funding vary across programs from highly structured to informal. The following questions are useful in examining this feature more carefully. Is the selection process formalized? Is a peer-review process used? Are projects selected according to publicly available criteria? What are the criteria? Do they include, for example, technical and/or economic merit, geographical or regional balance, collaboration between organizations, political affiliation, or other goals at the discretion of program administrators?

The ATP has a formalized, peer-review process for selecting projects. Selection criteria and application guidelines are published in a booklet called the Proposal Preparation Kit which is updated, re-issued periodically and widely disseminated. A selection board composed of technologists from government laboratories and agencies, business experts, and economists is established for each announced competition. Each project proposal is reviewed for the strength of its plan to pursue high risk research, its potential in delivering broad-based economic benefits to the nation and plans for diffusing results and bringing technologies developed during the project to commercial

fruition, the proposed organizational structure to accomplish project goals, commitment to carry the research through to commercialization, and experience and qualifications. The board chooses projects that score highest against these published selection criteria to receive financial assistance awards. The board does not consider geographic balance, political concerns, company relationships with staff, or other factors in its decision making process—only the "official" selection criteria.

The European Union's multi-annual Framework Program, which sets out the E.U.'s main scientific and technological objectives for a five-year period to tackle problems more effectively at the European level than by individual member states, encompasses several thematic programs. Applicants submit proposals to specific program announcements. Like the ATP, there is a step-by step published guide that provides applicants with general information on the submission and selection process. Proposal evaluators are given a set of formal, established criteria against which proposed projects are reviewed. Although detailed selection criteria differ across programs, there is a set of common selection criteria which are similar to ATP's in the focus on scientific and technical excellence, diffusion of technical results, and impact on the economy, but unlike the ATP there is no required plan for future commercialization. Moreover, there are two other important differences. The Framework Program requires transnational collaboration, as mentioned earlier. In addition, the Framework Program provides funding to projects which are aimed at serving goals other than the creation of new technologies, including training and mobility of researchers, and standards and measurements. Furthermore, other considerations such as the R&D priorities of member states are also taken into account, reflecting the political concerns to which the Framework Program must be responsive.

A new program in Japan called "Teiankobo" which translates into "proposal-based, new creative technology research and development program" was established last year in several ministries, including the Ministry of International Trade and Industry (MITI), and has different research foci depending on the ministry in which it sits. MITI's Teiankobo is administered by the New Energy and Industrial Development Organization (NEDO), a public corporation attached to MITI. Like the ATP and the Framework Program, MITI's Teiankobo also makes its selection process and criteria formal and publicly available (in Japanese). In NEDO's public request for proposals, guidelines are provided for applicants. These guidelines state that a screening committee established within NEDO will evaluate proposals submitted against specific screening criteria which are composed of five elements: fundamental, original, and innovative research; ripple effects on industry, the economy, and society; international significance with Japan taking a leading and guiding role; appropriateness of the plan and schedule of goals; and ability to implement the project. The guidelines also state that NEDO will consider the screening committee's deliberations to make the final selection of projects.

An approach that relies more on established, formal selection criteria may provide greater assurance that projects will be selected for their merit. Projects that are selected according to criteria other than technical and/or economic merit may deliver on these other objectives, but possibly at the cost of good technical and economic results—as would probably be the case if the selection process were not based on peer review, but on, for instance, political favoritism.

Public-Private Financial Arrangements

Cost-sharing arrangements are another constituent part of a program's architecture. What are the financial arrangements between the government and participants? Is the government providing a grant or a loan? Is the government a minority investor in the project or a majority investor? A program may be designed to provide all the costs of a research project or require that award recipients pay some portion.

The ATP is designed with a cost-sharing requirement. For single proposer projects, the ATP requires the award recipient to cover all indirect costs of the project, with the exception of large businesses which must cover a minimum of 60% of total project costs (direct and indirect)—a requirement that is effective beginning with 1998 awards to encourage large businesses to join in formal collaborative efforts. The ATP requires at least two for-profit industrial members in a joint venture project to contribute to the cost-share requirement of greater than 50% of total project costs.

Many analogues to the ATP have similar cost-sharing arrangements. U.K.'s LINK Scheme and Finland's TEKES both require a minimum of 50% cost share. The E.U.'s Framework Program requires at least 50% cost share from companies while university partners have all their costs paid by the government. Canada's TPC program, however, requires a higher cost-share typically between 70% and 75% of the eligible project costs, but not lower than 67%. The TPC program's higher cost-share requirement is understandable because it funds nearer-to-market projects, as mentioned earlier, and expects to recover its investment generally through royalties once a project is complete.

By setting or not setting a cost-share requirement, program administrators can influence the type of projects proposed. For example, by requiring some level of cost sharing, programs may find greater commitment on the part of the award recipient to carry out the project to term and pursue subsequent commercialization since their financial stake in the project provides them with a stronger incentive to realize a return on their investment. However, the larger the cost share required of industry—let's say, larger than the government's contribution like Canada's TPC program—the more likely firms are to propose projects that can deliver earlier commercial opportunities to gain a faster return on their investment (i.e., projects that are closer to market). Program administrators, in this example,

may find it more difficult to attract project proposals that will yield much greater social than private benefits. In contrast, programs that cover all the research costs may attract proposals that closely address societal objectives, but are weaker from a commercialization standpoint. Without making a financial contribution to the project, the companies funded may have less incentive to commercialize the results of the research. This situation may not be bad for programs that are aimed at creating new knowledge, but for programs aimed at stimulating economic growth or improving industrial competitiveness it may mean failure in achieving their mission if results fail to be commercialized in a timely way.

Conclusion

The ATP and its analogues are complex and intricate in their design, and their internal structures and inner workings have not been well understood by outside observers. Accordingly, our understanding of these specific national programs and their comparative similarities and differences has been limited. Without a lexicon with which to analyze and frame our understanding of these programs, our knowledge of such programs will remain superficial and evaluation and comparison of these programs will lack the necessary underpinnings. In an attempt to move the dialogue forward and to promote a more meaningful understanding of these programs, this paper analyzed program anatomy and constructed a vocabulary for understanding program design choices. It identified and discussed a representative sample of important program design features and provided examples of national programs embodying these design choices. This new lexicon and framework of analysis should improve our understanding of how these programs operate, will facilitate comparisons, and may even prove useful in conceptualizing the design of new programs or of fine-tuning and adjusting currently existing programs. This paper has taken the first steps, but further work needs to be done.

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Author Biography

Connie Chang is an Economist at the Advanced Technology Program of the Commerce Department's National Institute of Standards and Technology. She has been researching international counterpart programs for the ATP for the past several years. She received her master's degree in international management from the University of California at San Diego and bachelor's degree in economics from Wellesley College. She is currently pursuing a doctorate degree in technology policy and political economy from the Massachusetts Institute of Technology.

Book Reviews

Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness (1996). Washington: Council on Competitiveness. 145 pages. $25.00

The Council on Competitiveness describes itself as ". . . a nonpartisan, nonprofit forum of chief executives from the business, university and labor communities working together to set a national action agenda for U.S. leadership in global markets, technological innovation, and education and training that will raise the standard of living of all Americans" (p. 140). Names of its members and advisory council, listed at the back of the report give credence to their claim and show the diversity of talent that makes up the organization. Therefore, its statement on national R&D policy deserves attention.

This report has three objectives: to assess the current status of R&D in the nation, identify appropriate roles for all sectors in the R&D effort, and suggest policy guidelines to help fill some of the identified gaps. The assessment is deductive and based on case studies of six major industries: aircraft, automotive, chemical, electronics, information technologies, and pharmaceuticals. These cases comprise four-fifths of the report and, by themselves, provide interesting reading, for example, the section on aircraft covers interesting highlights of the Boeing 777 project and NASA's High Speed Research and Advanced Subsonic Technology projects.

The report debunks the linear model of innovation and the polarizing distinction between applied and basic science, emphasizing instead the complex and interactive nature of R&D. It suggests a three-way split of research types: short-term, low-risk; mid-term, mid-risk; and long-term, high risk. The first two categories are considered to be the acceptable realm of industry R&D, the last two of government R&D, and the third and final category for university R&D. The report suggests that this distinction will help inform a broader national debate on R&D goals and provide impetus for a more stable and consistent federal role in the national R&D effort.

The second major finding is that limited resources and the pressures of global competitiveness over the past 10–15 years have contributed to two outcomes—a significant restructuring of R&D activities away from corporate labs, toward suppliers and universities, and a refocusing of R&D toward shorter term market applications and away from longer term, higher risk projects. Centralized corporate labs have been downscaled, and companies are increasingly relying on first-tier suppliers, business units and universities to conduct R&D. This restructuring has reduced costs for the corporation, increased the rate of innovation, and brought R&D closer to the market and more in line with specific firm core competencies. Universities, feeling the pinch from continued declines in federal R&D spending, have gradually shifted their research toward short- and mid-term research needs in response to increased corporate funding. Government labs have also been scrambling to readjust their research efforts toward civilian niches that focus more narrowly on specific areas of R&D that, at least in theory, provide greater support for U.S. competitiveness.

The third major finding, and overall theme of the report, is the expansion of inter- and intra-sectoral R&D partnerships. By far, the single most obvious response of all three sectors to limited resources has been an increasing reliance on alliances that simultaneously reduce R&D costs to individual companies, and provide access to external expertise through leverage of their own internal talent. "[Partnerships] vary widely in scale and scope, from company-to-company tie-ups to complex networks involving all three of the stakeholders in the innovation process" (p. 3). With the six case studies as evidence, the Council considers the restructuring to be significant enough to call it a new paradigm for R&D.

The fourth and final finding is simple—the trends discussed above will continue. All sectors will experience increased resource constraints. Corporations will further devolve and sharpen their R&D roles and responsibilities. There will be a subsequent increased emphasis on short-term, low-risk R&D across the nation. And the structural movement toward partnership as a means of leveraging defined skills and expertise, while maintaining multidisciplinary approaches to problems solving, will deepen.

The report provides a set of policy guidelines for industry, government and academia. Industry should increase its investment in U.S. R&D, both in response to global competitiveness challenges and because federal funding is on the decline. Inherent barriers to collaboration and partnership in the private sector need to be reduced—especially in the areas of long-term research. For government, the council pushes support for critical technologies with civilian applications, promotion of partnerships, regulatory and tax support for R&D, tighter scoping of missions and budgets, and finally, continued support of universities. Academia needs to strengthen its role as a producer of human capital and as a partner to industry and government.

While there are no real surprises in these assessment, findings or guidelines, *Endless Frontier, Limited Resources* is informative and speaks knowledgeably about the current and future status of R&D efforts in the U.S. Its policy guidelines are relatively balanced, favoring few changes in the current system but offering a few tweaks to maintain or extend the competitive position for U.S. industry. Nevertheless, there are omissions and oversights that need to be addressed.

The report speaks broadly to a need for the nation to develop a consensus on R&D goals and critical technologies, it speaks specifically to the immediate need for all

sectors to push partnerships. Consensus addresses planning operations, while partnering, as is presented in the report, describes a response by all three sectors to limited resources in a competitive environment. The report does not reconcile these two very different functions, preferring instead to concentrate on mechanisms for streamlining and simplifying the partnership process. National goals are assumed to naturally embody critical technologies and economic competitiveness. I submit that national goals are more complex.

In addition, there is a large bias in the cases selected for analysis. All six industries studied are large, well established, and very competitive in global markets. Only in two small sections of the electronics case—optoelectronics and flat panel displays—are there concerns raised about sunrise industries and U.S. dominance. Surely partnerships, especially between government and academia, are critical in these areas and differ in recognizable ways from partnerships in other industries. The report does an insufficient job of guiding planning with respect to different characteristics of the industries involved.

The industries and the cases themselves fail completely to address limitations of energy, natural resources, and clean environment. These industries are treated in a traditional way—according to the government department represented either as a source of partnering or as a source of regulation. It is disappointing, in an era when economic resources represent only one portion of the limitations and drivers for partnership, that the Council on Competitiveness could not better address how non-economic forces are affecting partnerships and national R&D objectives. Furthermore, the report lost an opportunity by ignoring what probably represent some of the most important future research frontiers.

Finally, the report is unsure about how to treat basic science research. The title "Endless Frontiers . . ." appeals to the cultural legacy left by Vannevar Bush, that basic research provides the foundation for economic growth, productivity improvements and the betterment of society. While the authors choose to apply the term more broadly than initially intended—to all R&D rather than only to basic science,[1] and while they attempt to reject the distinctions between basic and applied research, they remain nostalgic about the notion of an endless frontier. On the one hand, the report gives short shrift to basic research in its conceptual framework and in policy guidelines, preferring different terminology and a less epistemological approach. On the other hand, the report uses statistics on declines in funding levels for basic research funding to bolster concerns about the trends toward a declining fundamental research base. Throughout the report the authors seem undecided about how basic research relates to their own framework.

Part of the reason for the confusion is that basic research is a public good that serves multiple social purposes including economic competitiveness. Basic science research and public willingness to support basic science research is an important and unique part of the U.S. culture. It is one element that has made American universities and the nation strong. It is a model that often requires the passage of decades before benefits (direct and indirect) are realized. It is also a model that requires good management. However, funding of basic research needs to be undertaken by government (and other sources if possible) to support long-term economic competitiveness, further human knowledge, feed our spirit of curiosity, and improve society. Surely, it does not behoove us to reject the entire model in favor of short-term economic competitiveness—regardless the resource constraints. Probably the authors know all that. Otherwise the title would have been "Limited Resources, Limited Frontiers."

Eric Welch
Center for Technology and Information Policy
Syracuse University

[1]Bush, Vannevar. 1945. Science: The Endless Frontier. Washington, D.C.: The National Science Foundation.

Stokes, Donald E. (1997). **Pasteur's Quadrant: Basic Science and Technological Innovation.** Washington: The Brookings Institution. 180 pages, notes, index. $38.95

Half a century ago, Vannevar Bush forged the fundamental views towards science and research in the process of technological change that still prevail today. These views continue to play a pivotal role in directing contemporary science policy in this country and elsewhere. The purpose of this insightful book is to challenge the conventional wisdom about the fundamental links between basic and applied scientific research. Most importantly, Stokes rejects the linear model suggesting that science is the driving force generating technological innovation. Instead, Stokes develops a compelling set of examples from the U.S. and Japanese experience to argue that the links between science and technology are interactive. An important policy conclusion is that applying the linear framework will tend to distort science policy. For example, it is widely accepted that basic science succeeds only to the degree that it is insulated from commercial applications.

In the first chapter Stokes traces the origins of the U.S. postwar science policy paradigm and succinctly describes the linear model of science and how it evolved into becoming the defining conceptual framework for American science policy. The second chapter traces the roots of science policy back to older traditions in Europe and even the ancient Greeks. The third chapter documents how the linear model was transformed into becoming the underlying framework for U.S. postwar science policy. This transformation has resulted in what the author terms as "the disarray of science and technology policy . . . especially in the United States," and is described in Chapter Four. In particular, this disarray has been the result of the end of the

Cold War, globalization, and the political budgetary process. However, Stokes closes the chapter by calling for a renewed compact between science and the government. The concluding chapter of the book considers the role of basic science in the context of American democracy.

This is a rare book that will lead both policy makers and scholars to rethink many of their basic assumptions about science policy. The book is thoughtful, provocative and rewarding to read. It will prove to be invaluable to both experts in the field as well as those becoming acquainted with science policy for the first time.

David B. Audretsch
Policy Research Center
School of Policy Studies
Georgia State University

Books Received

Agre, Philip E. and Marc Rotenberg, eds. (1997). **Technology and Privacy: The New Landscape.** Cambridge, MA: MIT Press. 325 pages, index, $25.00. The ten essays in this book present a conceptual framework for analysing privacy issues in the face of developments in such things as the spread of networking, major increases in communication bandwidths, and new techniques of cryptography and surveillance. Contributors are from diverse professional backgrounds, including academia, law enforcement, industry, and consulting on aspects of privacy, and include experts in communication, political science, economics, and the underlying technologies.

Bradley, Stephen P. and Richard L. Nolan, eds. (1998). **Sense and Respond: Capturing Value in the Network Era.** Boston, Harvard Business School Press. 350 pages, notes, index. $45.00. Summarized from page proof copy in the Spring 1998 issue of *JTT*.

Bugliarello, George et al., eds. (1996). **East-West Technology Transfer: New Perspectives and Human Resources.** Dordrecht: Kluwer Academic Publishers. 318 pages, index. $149. The book comprises 19 papers from a NATO Advanced Research Workshop, co-sponsored by the Scientific and Technical Research Council of Turkey, dealing with technology transfer between the Cold War NATO nations and countries of the former Soviet block. Papers include discussions of legal issues, national technology policies, personnel requirements, and the experiences and problems of several nations, including Russia, Kazakhstan, the Kyrghyz Republic, Uzbekistan, the Central and Eastern European nations, Finland, Sweden, Turkey, and the United States.

Chorafas, Dimitris N. (1998). **Transaction Management: Managing Complex Transactions and Sharing Distributed Databases.** New York: St. Martin's Press. 322 pages, bibliography, index. $65. The Preface describes this book as "intended to appeal to information technology managers and systems experts confronted with the implementation of a transactions environment." Based on research in over 100 companies in the U.S., Europe and Japan, it provides advice on the management of complex transactions and share distributed data bases on client servers and the internet. Long and global transactions are emphasized.

Feinstein, Charles and Christopher Howe, eds. (1997). **Chinese Technology Transfer in the 1990s: Current Experience, Historical Problems and International Perspectives.** Cheltenham, UK: Edward Elgar. 254 pages, index. $85.00. This book presents papers by twelve academicians, six Chinese and Six British, who participated in a 1995 seminar to examine scientific policy, R&D, and technology transfer in the People's Republic of China, with special reference to the reform policy and encouragement of foreign direct investment. The British participants focused primarily on theoretical, historical, and international aspects of technology transfer and economic development, while the Chinese discussed their nation's policies, problems, and prospects, including unresolved issues currently under debate.

Harryson, Sigvald (1998). **Japanese Technology and Innovation Management: From Know-how to Know-who**. Cheltenham, UK: Edward Elgar. 272 pages, bibliography, index. $80.00. The theme of this book is that companies in high-tech markets can no longer rely on their own specialized technical competence for timely and appropriate responses to competitive and market shifts, but must develop the capability to access and acquire the most current knowledge—i.e., draw less on internal "know-how" and more on external "know-who" to borrow from. This involves open sharing of ideas, technologies, and human resources. The argument is bolstered by three in-depth case studies, of Canon, Sony, and Toyota.

Howells, Jeremy and Jonathan Michie, eds. (1997). **Technology, Innovation and Competitiveness**. Cheltenham, UK: Edward Elgar. 256 pages, index. $80.00. Technology, innovation, and competitiveness are considered from an international perspective in the nine papers comprising this book, as these papers were presented at the first of a series of "Euroconferences" entitled "The Globalization of Technology: Lessons for the Public and Business Sectors." Topics covered include the globalization of research and technology, the effects of this globalization on the product life cycle, the role of financial institutions in the global economy, the consequences of finance for structural competitiveness, and the policy implications of recent developments.

Iansiti, Marco (1998). **Technology Integration: Making Critical Choices in a Dynamic World**. Boston: Harvard

Business School Press. 249 pages, bibliography, index. $35.00. Technology integration, or the process of choosing the appropriate combination of technologies to integrate into a product from a large and complex assortment available, is often the key feature distinguishing successful from unsuccessful product development performance, according to the basic argument of this book. A study of the experiences of more than fifty companies in the software and computer industries concludes that technological choices made before the product development stage are crucial to the end results. Although the book focuses on the computer industry, the findings are considered relevant to any firm implementing novel technologies.

Jasanoff, Sheila, ed. (1997). **Comparative Science and Technology Policy**. Cheltenham, UK: Edward Elgar. 673 pages, name index. $235. This book consists of reprints of 27 recent leading articles on science and technology policy plus an editor's Introduction, organized into six topical areas: science, technology and the state; governmental support for science; cross-national perspectives on technology policy; cultures of innovation; regulatory politics and policy; and international influences and national policy. Contributions are from various disciplines including economics, political science, law, and science and technology policies, covering a number of divergent views.

National Academy of Engineering (1998). **Frontiers of Engineering: Reports on Leading Edge Engineering from the 1997 NAE Symposium on Frontiers of Engineering.** Washington: National Academy Press. 135 pages. $29.00. This book is the third and most recent in a series containing extended abstracts of the presentations made at the NAE symposia, Frontiers of Engineering. It contains descriptions of new research and technologies, and the benefits they may bring, in biomechanics, sensors and control for manufacturing processes, safety and security issues, decision-making tools for design and manufacturing, and intelligent transportation systems.

Poterba, James M., ed. (1997). **Borderline Case: International Tax Policy, Corporate Research and Development, and Investment.** Washington: National Academy Press. 168 pages, index. $39.95. In his introduction the editor of this volume notes that as the trend toward global firms continues, one vital feature of the business environment that remains dependent on a firm's nominal nationality is its tax treatment. The book contains eleven papers presented at a 1997 conference held at the National Academy of Sciences, exploring the impact of the U. S. tax code on basic research outlays, expenditures on product and process development, and plant and equipment investment in the international activities of U.S.- and foreign-based firms, including prescriptions and prospects for tax reform.

Victor, Bart and Andrew C. Boynton (1998). **Invented Here: Maximizing Your Organization's Internal Growth and Profitability: A Practical Guide to Transforming Work**. Boston: Harvard Business School Press. Approximately 242 pages, notes. $29.95. The core of this book is a discussion of how organizational knowledge can transform work in an era of rapid technological change, economic growth, and increasing globalization of markets. The authors contend that managers must regularly assess their own firms' existing knowledge bases and distinctive competencies rather than rely on the experiences of other firms or the general strategies advocated by management consultants and academicians. The argument is bolstered by a number of examples from a highly diverse set of companies. (page proof copy)

The *Journal of Technology Transfer* welcomes book reviews prepared by its readers. A reader interested in submitting a review of any of the above listed books is encouraged to contact the Book Review Editor at the address shown on the inside rear cover. Reviewers will be sent complimentary copies.

Reader Participation Survey

A forthcoming issue of the *Journal* will publish a two-part article by Lesley Cameron, William Finan, and William Morgan of the economic consulting firm Horst, Frisch, Clowery & Finan. The articles will provide an overview of international tax considerations, especially issues related to what is called transfer pricing, and their influence on the structure of technology transfers. The first part will discuss the general principles of the tax treatment of technology transfers, especially among related companies. The second part will provide a series of case studies that illustrate how these principles are applied to a hypothetical company facing tax decisions related to cross-border intercompany technology transfers. Needless to say, tax issues are complex and can frequently be difficult to grasp by non-tax professionals. Hence, we think a practical guide to tax considerations for readers of the *Journal* by these economic experts will provide a valuable primer for our readership.

In conjunction with the publishing of these articles, we are conducting a survey of our readers to gain insight into their exposure to the issues the authors plan to address. Cameron, Finan, and Morgan will summarize the survey results in their articles.

Please e-mail your responses to hfcf@hfcf.com.

1. A. Please identify your general professional affiliation below.
   Government Education Private Sector

   B. If private sector, please identify your industry (e.g., electronics, automotive, aerospace, etc.).
   _____

2. Does your role include any of the following responsibilities?

   A. Negotiating contracts or licenses that involve the transfer of technology to or from unrelated companies (third parties)?
   Yes ____ No ____

   B. Making final decisions regarding contracts or licenses with unrelated companies?
   Yes ____ No ____

   C. Preparing quantitative analyses (e.g., make/buy decision) of the implications of technology transfer agreements with unrelated companies?
   Yes ____ No ____

3. Have you ever been questioned by your company's tax group regarding technology transfer issues?
   Yes ____ No ____

4. Does your company evaluate financial results on a before- or after-tax basis in deciding about technology transfer?
   Yes ____ No ____

5. Are you familiar with your company's legal structure?
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In advance, the editors thank you for your participation in this reader survey.

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- new organizational arrangements or experiments
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Journal of Technology Transfer
College of Integrated Science and Technology
James Madison University
Harrisonburg, VA 22807
Phone: (540) 568-2790
FAX: (540) 568-2761
E-mail: j-tech@jmu.edu

Dr. Albert N. Link, Co-Editor
Journal of Technology Transfer
Department of Economics
University of North Carolina at Greensboro
Greensboro, NC 27412
Phone: (336) 334-5146
FAX: (336) 334-4089
E-mail: al_link@uncg.edu

Book reviews. All correspondence regarding book reviews should be addressed to:

Dr. William L. Baldwin
Department of Economics
6106 Rockefeller Hall
Dartmouth College
Hanover, NH 03755
E-mail: william.l.baldwin@dartmouth.edu

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