PART II:

APPLYING EVALUATION METHODS TO ATP

Part II examines ATP's specific use of the evaluation methods that were presented in a general way in Chapter 2. Modeling underlying program theory is presented first, because it helps define how a program works. Following sections present the survey method, case study, econometric/statistical methods, expert judgment method, bibliometrics, and several newly developed evaluation methods.

The emphasis in this section is the application of these methods and not specific findings from the studies other than to illustrate their implications. A crosscutting analysis of study findings is provided in Part III.

CHAPTER 4

Modeling and Informing Underlying Program Theory

As discussed in Chapter 2, the modeling and informing underlying program theory is an essential prelude to program operations, an early stage complement to other management and evaluation efforts, a building block in the design of a long-term comprehensive evaluation program, and an ongoing source of continuous organizational learning. Clarifying and validating a program's underlying concepts and the analytical linkages among its various elements is an important part of an agency's overall program evaluation strategy. Yet, pressures for quick responses to questions about program activities can lead program administrators to neglect program theory and the investigation of program dynamics.

At ATP, modeling and informing underlying program theory has yielded information critical to the program's survival, shape, and success, and has become a mainstay of ATP's evaluative program. Identifying the characteristics of multiple, complex, causal paths has been an important part of ATP's evaluation plan because program modeling strategy involves influencing both the immediate and proximate determinants of firm and industry behavior. The combination of external challenges and internal commitment to documentation of results has produced a program noteworthy among federal government programs in the level of attention it has devoted to understanding and documenting the program's effects.

This chapter details ATP's use of analytical and conceptual modeling to explore basic concepts and of underlying program relationships, to condition expectations and set benchmarks for performance, and to refine dominant theoretical paradigms. Unavoidably, the numerous relevant concepts and subtopics drawn from multiple sources add complexity to the treatment. To assist the reader, the major themes and the reports and papers used to amplify each theme are listed in Table 4–1, presented in the order discussed in the chapter, and with the particular contribution to underlying concepts and theory noted. The primary purpose of several of the documents cited here was not to explicate underlying program theory, yet they are included because they also made significant contributions to understanding ATP's workings. Table 4–1 is intended as a quick reference and roadmap through the chapter.

*Table 4–1. Twenty-Two Studies and Papers Modeling and Informing Underlying Program Theory**

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Concepts, models, metrics, and paths			
Modeling Spillovers Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program	1996	Jaffe	This key background document conditioned ATP's definition of success, its understanding of market, knowledge, and network spillovers, and provided guidance on how to increase spillovers, a key aspect of ATP's rationale.
Modeling ATP Publicly supported non-defense R&D: the USA's Advanced Technology Program	1997	Spender	The 3-D model shows how ATP contributes to social welfare by yielding a combination of increased knowledge, private benefits, and large spillovers, while avoiding corporate welfare charges.
Modeling ATP Advanced Technology Program's Approach to Technology Diffusion	1999	Ruegg	The 2-path impact model of ATP includes a direct path through which ATP has its greatest ability to influence technology development for U.S. benefit, and an indirect path important for generating knowledge spillovers.
Identifying Metrics Measuring the Economic Impact of the Advanced Technology Program: A Planning Study	1992	Link	An early look at potential program performance metrics helped condition expectations of ATP's input, output, and outcome metrics and plans for data collection.
Understanding Collaboration Determinants of Success in ATP-Sponsored R&D Joint Ventures: A Preliminary Analysis Based on 18 Automobile Manufacturing Projects	2002	Dyer and Powell	A model of factors important to joint venture success and the relationship of factors affecting operational costs (decreasing success) and greater trust among participants (increasing success) was a contributing input to ATP's growing understanding of how collaborations work.

Table 4–1. (Cont'd)

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Conditioning expectations through studies of private-sector behavior			
Measuring Market Spillovers Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities	1996	Mansfield	Benchmarking of ATP against market spillover rates of privately financed innovations, and demonstration of high error rates in prospective private economic assessments influenced expectations for ATP's own performance. Adaptation of Mansfield's model of market spillovers to ATP provides a principal method of estimating market spillover benefits from ATP projects.
Funding Gap Capital Formation and Investment in Venture Markets: Implications for the Advanced Technology Program	1999	Gompers and Lerner	Finding that large increases in private-sector venture funding is highly concentrated and appears to leave funding gaps, together with 7 case studies concluding that ATP added, rather than substituted for private funding, contributed to the view of ATP as a legitimate and needed additional funding source in technology development.
Funding Gap Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage, Technology-Based Projects	2000	Branscomb et al.	Examination of risk management in private firms showed no silver bullet for ATP's use. Study of funding decisions of venture capitalists and firms supported the concept of a "valley of death," or funding gap, lying between basic research and commercialization, which public funding of high-risk, enabling technology development can help to bridge without driving out private-sector funding.
Funding Gap Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development	2002	Branscomb et al.	Provides a better understanding of the sources of investments into early-stage technology development projects. Includes a distribution of funding for early-stage technology development across different institutional categories. Found that most funding for technology development in the phase between invention and innovation comes from individual private-equity "angel" investors, corporations, and

continued on next page

Table 4–1. (Cont'd)

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Funding Gap Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development (Cont'd)			the federal government, not venture capitalists. Also found that conditions for success in science-based, high-tech innovation are strongly concentrated in a few geographical regions and industrial sectors, indicating the importance in this process of innovator-investor proximity and networks of supporting people and institutions.
Funding Enabling Technologies Advanced Technology Program's Commercialization and Business Planning Guide in the Post-Award Period	2000	Servo	Guide assists ATP award recipients during the post-award period to increase their chances of attracting funding to complete technology development and commercialize technologies. Includes a diagram showing how ATP funding fits into the larger framework of funding sources for innovating firms which helps to define the unique funding position of ATP. Also, diagrams related to commercializing from technology platforms amplified in a business sense the concept of enabling technology.
Conditioning expectations through studies of other public sector programs			
State Programs Reinforcing Interactions between the Advanced Technology Program and State Technology Programs; Vol. 1: A Guide to State Business Assistance Programs for New Technology Creation and Commercialization	2000	Schachtel et al.	Assessing where state programs focus their assistance to businesses showed them to be mostly downstream of ATP, suggesting complementary relationships rather than overlapping functions.
State Programs Reinforcing Interactions between the Advanced Technology Program and State Technology Programs; Vol. 2: Case Studies of Technology Pioneering Startup Companies and Their Use of State and Federal Programs	2000	Feldman et al.	Case studies of firms receiving both state and federal assistance reinforced the view of a complementary use by companies of ATP, state, and other federal programs in developing technologies.

Table 4–1. (Cont'd)

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Foreign Counterpart Programs A New Lexicon and Framework for Analyzing the Internal Structures of the U.S. Advanced Technology Program and its Analogues Around the World	1998	Chang	A framework of key program features is a useful tool for comparing ATP with similar programs abroad, both to learn from them and to meet legislated tests of foreign eligibility for ATP participation. Comparisons to date show ATP as part of a larger movement among nearly all of the world's industrialized countries to foster technology development through public-private partnership programs.
Evaluation in the United States and Abroad Papers and Proceedings of the Advanced Technology Program's International Conference on the Economic Evaluation of Technological Change	2001	Spivack, ed.	An ATP-hosted international conference on economic evaluation revealed much more pressure on U.S. partnership programs to provide quantitative measures of impact than in Europe where counterpart programs appear to have greater acceptance as instruments of technology policy and an emphasis more on qualitative evaluation.
Using Foreign Program Data to Test Models Measuring the Impact of ATP-Funded Research Consortia on Research Productivity of Participating Firms	2002	Sakakibara and Branstetter	To test a model designed for ATP and applied to it, the study applies the model using Japanese program data to take advantage of the longer period of operation and the greater data availability.
Using Foreign Program Data to Test Models R&D Policy in Israel: An Overview and Reassessment	2000 draft	Griliches et al.	To test a model designed for ATP, the study applied it using Israeli program data to take advantage of the longer period of operation and the greater data availability.
Conditioning expectations about program time horizons			
Hypothetical Timelines "Assessment of the ATP," The Advanced Technology Program: Challenges and Opportunities	1999	Ruegg	A framework of ATP's time horizon showing expected outputs and outcomes and their timing to helped condition stakeholder expectations of the program and define the program's scope with respect to time.

Table 4–1. (Cont'd)

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Actual Timeline Examples Performance of Completed Projects: Status Report 1	1999	Long	Two accounts of actual project time horizons in the context of the general framework helped to condition expectations about the likely range of variation in the timing of different technologies within the program's scope.
Testing dominant paradigms			
Productivity Effects R&D Policy in Israel: An Overview and Reassessment	2000 draft	Griliches et al.	This work is one of several studies challenging the dominant paradigm that government funding adversely affects firm productivity by showing a positive effect of counterpart Israeli programs on productivity.
Productivity Effects Measuring the Impact of ATP-Funded Research Consortia on Research Productivity of participating Firms	2002	Sakakibara and Branstetter	Taking a different approach from the previous study, this study also showed a positive impact of ATP-funded consortia on research productivity of firms.
Productivity Effects Program Design and Firm Success in the Advanced Technology Program: Project Structure and Innovation Outcomes	2002	Darby et al.	Taking yet a different approach than the previous two, this study also showed a positive impact of ATP funding on firm productivity.
Technology Diffusion Advanced Technology Program's Approach to Technology Diffusion	1999	Ruegg	Explicit models of ATP projects' organizational structure, together with a list of ATP program features, support a logic-based argument that ATP projects have an increased probability of being commercialized.
Technology Diffusion Temporary Organizations for Collaborative R&D: Analyzing Deployment Prospects	2000 draft	Przybylinski et al.	Models and case studies showed why new technologies differ substantially in their prospects for commercialization, and suggested anticipatory steps to reduce inherent and predictable barriers.
Effects of University Participation Universities as Research Partners	2002	Hall et al.	An analysis of university participation in ATP projects suggested that it is associated with pursuing new science, more difficulty in project research, and lower rates of project termination.

Table 4–1. (Cont'd)

REPORT OR PAPER TOPIC AND TITLE	DATE	AUTHOR	CONTRIBUTION TO PROGRAM THEORY
Effects of University Participation Public-Private Partnering and Innovation Performance Among U.S. Biotechnology Firms	2000 draft	Kogut and Gittelman	Another look at the effect of university participation on firm innovation supported a positive role for universities in firm partnerships.
Knowledge Flows Between Firms and Universities Study of the Management of Intellectual Property in ATP-Grantee Firms	2000 draft	Liebeskind	A dominant paradigm emphasizes knowledge flows from university to industry. But this analysis of universities in ATP projects with firms suggested an important "inverse" route for knowledge dissemination: from industry to universities.

**Note:* Three of the studies are listed more than once because they address multiple concepts.

Concepts, Models, Metrics, and Paths Connecting Program Activities to Intended Impacts

Recognizing that it fell between the conventional poles of federal support of basic research on the one hand, and of mission-oriented basic and applied research on the other, ATP quickly sought to clarify its basic concepts, to help explain how it works, and to develop improved models for analysis. A variety of seminars, roundtables, staff papers, presentations, and commissioned studies were used to flesh out concepts, models, and pathways of the program, and point toward the best evaluation methods.

Economic Spillovers

The concept of spillovers is central to ATP and implicit in the argument that ATP will help address under-investment in generic technologies by the marketplace. An "economic spillover"[60] is the excess return to society of an investment over the private return captured by the investing firms. The presence of particularly large spillovers may cause private firms to invest less than is socially optimal because too much of the benefit escapes them. Spillovers provide a primary justification

[60] An economic spillover is also known in economists' jargon as a "positive externality."

Table 4–2. Classification of Spillovers

SOURCE OF SPILLOVER	DEFINITION	METHODS OF OCCURRENCE (EXAMPLES)
Knowledge spillovers	Knowledge created by one agent is used by another without full compensation.	✓ Reverse engineering of products ✓ Firm abandons R&D effort but knowledge from it is accessible to other economic actors ✓ Publications ✓ Patent disclosures ✓ Researcher mobility
Market spillovers	Market dynamics cause some of the benefits for a product or process to flow to market participants other than the innovating firm.	✓ Prices for a new or improved product do not fully capture its superior quality or performance relative to what was available before ✓ Lower production costs lead a company to lower its selling price, making the customer better off
Network spillovers	Network spillovers arise if the economic value of a new technology is an increasing function of the development of a set of related technologies.	✓ A "coordination problem" is overcome, whereby firms coordinate their efforts for a larger cause ✓ A sufficient fraction of a set of related research projects is completed to create a critical mass needed to increase commercial payoff to them all

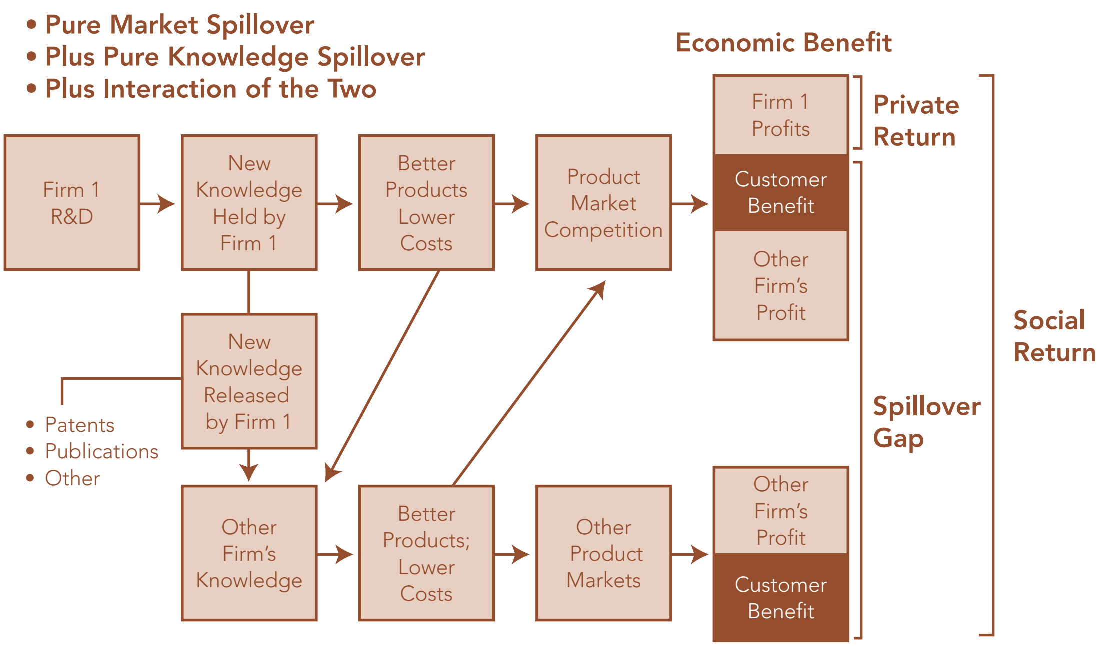
Source: Summarized from Jaffe, *Economic Analysis of Research Spillovers,* 1996.

for public intervention to increase investment in R&D. A closely related concept is "inappropriability," which refers to the inability of an investor to capture, or "appropriate," the fruits of his or her investment.

To delve deeper into the subject of spillovers and their implications for the program, ATP commissioned Adam Jaffe, economics professor at Brandeis University and member of the National Bureau of Economic Research (NBER), to prepare an economic analysis of research spillovers.[61] Noting that spillovers

[61] Adam B. Jaffe, *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program,* NIST GCR 97–708 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Figure 4–1. Private and Social Returns to R&D: Pure Market Spillover, Plus Pure Knowledge Spillover, Plus Interaction of the Two



Source: Jaffe, *Economic Analysis of Research Spillovers*, 1996.

Firm 1 invests in R&D, generating new knowledge that it uses to improve its products or lower its production costs. Assuming the firm successfully commercializes the results, market competition causes the value of some of firm 1's improvements to be captured by its customers in the form of lower prices or higher quality. This effect alone would cause a spillover gap equal to the customer benefit. But the figure shows other effects. The first downward pointing arrow indicates that knowledge spillovers flow from firm 1's knowledge base to other firms through disembodied outputs such as papers and patents. The second downward pointing arrow indicates that knowledge also passes from firm 1 to other firms through research results embodied in its new commercial products and processes. The third arrow, which points upward, indicates that at least some of the firms benefiting from the knowledge spillovers are competitors of firm 1, who then introduce cheaper or better products into firm 1's markets, taking some of its profits and creating some additional customer benefits. Meanwhile, these other firms may also introduce improved or lower cost products and process into their own markets, resulting in firm profits and customer benefits. As Jaffe observes, "...the combination of knowledge spillover with competitive interaction increases the spillover gap both by *raising* the social return and *lowering* the private return." (p. 17) have been of interest to economists for several hundred years, Jaffe pointed out that R&D activities of private firms have been shown to generate spillover benefits; hence, ATP should be expected not only to fund R&D that generates spillover benefits, but R&D that yields higher-than-average spillovers.

Jaffe's work identified three different sources of spillovers relevant to ATP—knowledge spillovers, market spillovers, and network spillovers—and noted that the three interact synergistically to increase their combined effect. Table 4–2 defines each source of spillovers and gives examples of how each occurs. Figure 4–1 illustrates how knowledge and market spillovers interact and may lead to a gap between social and private returns.

In drawing the implications of spillovers for ATP, Jaffe identified factors that he saw associated with higher spillovers—a desirable feature from ATP's point of view. Table 4–3 lists some of these factors. According to Jaffe, ATP could improve its ability to select projects with greater-than-average spillover potential by acting on this information. This study gave ATP a model and specific guidance for increasing its effectiveness.

Table 4–3. Factors Increasing the Likelihood of Spillovers

FACTOR	FAVORABLE TO MARKET SPILLOVERS	FAVORABLE TO KNOWLEDGE SPILLOVERS	FAVORABLE TO INTERACTIONS OF KNOWLEDGE AND MARKET SPILLOVERS
Highly competitive markets	+		
Infrastructure technology	+		+
Difficult-to-protect innovation	+		+
Co-specialized assets important but innovators lack them	+		
Licensing important	+		
Multi-use technology		+	
Path breaking technology		+	
Useful knowledge generated even if project fails in objectives		+	
Difficult-to-keep-secret innovation		+	

Source: Compiled from information presented in Jaffe, *Economic Analysis of Research Spillovers*, 1996, pp. 42–44.

Descriptive Models of ATP

Models have more than analytical value; they can also help communicate a program to stakeholders. ATP staff developed several models to help explain the program's mission to a diverse audience. These models were used to explain and discuss the program in settings such as policy forums, internal strategic planning sessions, and ATP workshops.

The Three Dimensions of ATP's Mission

Modeling by J-C Spender, UK Open University Business School, helped ATP solidify its internal perspective and explain its dynamics.[62] The three dimensions shown in Figure 4–2 embody three main ideas that underlay ATP's enabling legislation: scientific and technical knowledge gains (axis labeled Technical Knowledge), commercial gains and improved competitiveness of U.S. companies (axis labeled Private Returns), and broadly based spillover benefits to the nation at large (axis labeled Public Gains). The figure is a conceptual illustration, not intended for quantification.

In describing the program, Spender, the diagram's author, speaks of ATP's goal as "promoting trajectories through an innovation space formed by partnership between the USA's three institutionally distinct modes of scientific and technological innovation: scientific research; private enterprise; and, public-sector management of society's public goods."[63]

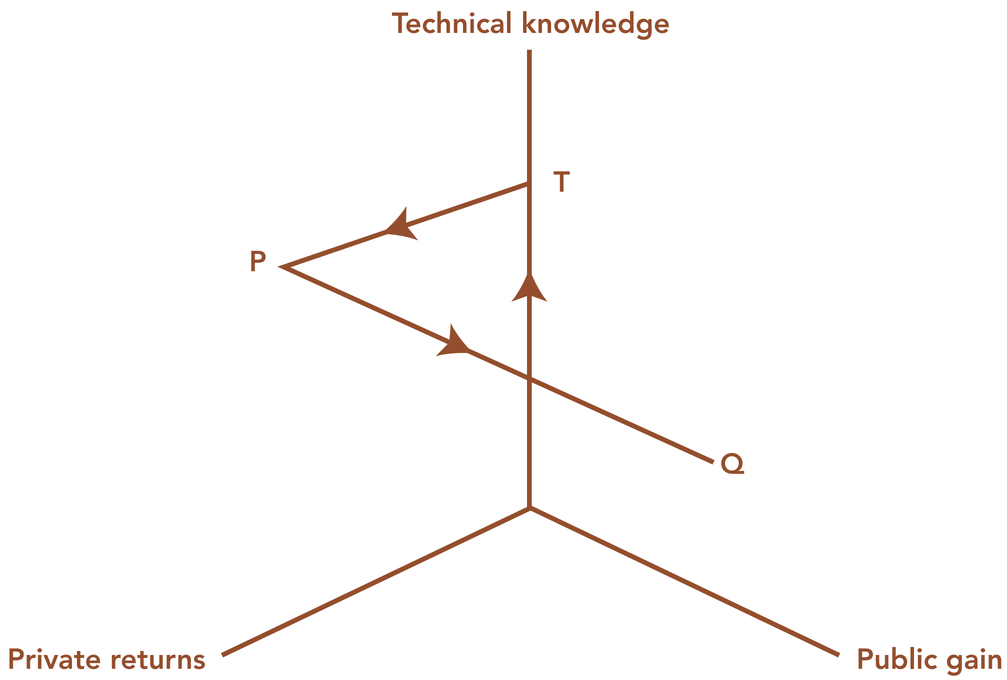
Spender's framework also has applicability in addressing critics' complaint that ATP represented "corporate welfare." According to Spender, charging that ATP is "corporate welfare" is to mistake, with reference to Figure 4–2, the point P for the point Q:

> Critics are correct in the sense that market-driven firms are being subsidized and are therefore benefiting, but off the mark in the sense that the point P is incidental. It indicates only the agent's incentive to act on ATP's behalf, not the social result of its activity. Ultimately the project's success must be measured in terms of the point Q (p. 49).

[62] J-C Spender, "Publicly Supported Non-Defense R&D: The U.S.A.'s Advanced Technology Program," *Science and Public Policy,* February: 45–52, 1997.

[63] Ibid., p. 45.

Figure 4–2. Three Dimensions of ATP and the "Journey to Q"



In concept, technical progress is measured in the diagram along the axis labeled **Technical Knowledge**, net benefits to the awardee from commercial activity along the axis labeled **Private Returns**, and net spillover benefits to others along the axis labeled **Public Gain**. The dimensions' orthogonality illustrates the independence of these outcomes (i.e., technological advance does not necessarily lead to economic activity, and commercial activity does not necessarily lead to public interests). The point Q depicts a desirable outcome for ATP—the end point of a project trajectory producing a combination of knowledge gains and net benefits to the awardee that are exceeded by large net spillover benefits to others in the economy.

Source: Spender, "Publicly Supported Non-Defense R&D: The U.S.A.'s Advanced Technology Program," 1997.

In addition to being useful in explaining the program's design to external constituencies, Spender's model also helped to develop a common perspective among ATP's functional staff: primarily scientists and technologists, business specialists, and economists. In the early to mid-1990s, combining staff from these fields in a single unit was still relatively new in business and government, and there was a distinct learning curve for the staff. As Spender puts it:

> ATP draws the participants into a common framework even if the innovative activity may not be comprehensible to those not institutionalized into the appropriate professional environment. Business experts are unlikely to appreciate the niceties of the research scientist's problems or respect the professional judgments required, especially where the levels of technical risk are high. Likewise, even though ATP seeks low-risk commercialization and public-goods effects, the complexities and subtleties of the social and economic works in which these arise are often puzzling to scientists. (p. 50)

ATP's Two Paths to Impact

Looking for a more succinct way to explain the program to diverse audiences, and specifically to provide context for examples of project impacts, ATP began to use the "two-path" diagram reproduced in Figure 4–3, which depicts direct and indirect paths to program impact.[64] The "direct path" represents the commercialization route of the award-recipient and its close collaborators to capture private benefits and generate market spillovers, as well as possible knowledge spillovers as others reverse engineer their products and processes. The "indirect path" represents the main route to knowledge spillovers: award-recipient publications, presentations, interactions, patents, and mobility of researchers among organizations, allowing others to gain knowledge from the funded research without paying for it. If these other organizations use the knowledge obtained for economic gain, benefits from knowledge spillovers result.[65]

The direct path has special significance because it allows ATP directly to encourage U.S. businesses to accelerate development, commercialization, and use of new technologies. The indirect path may ultimately prove to be even more important than the direct path in its generation of benefits, but it tends to

[64] The implication of the diagram is that these are linear relationships. In practice, ATP's evaluation design was predicated on an understanding that the above relationships were likely to be neither linear nor describable as two singular pathways; however, these simplifications were made for the purposes of exposition.

[65] R. Ruegg, *Advanced Technology Program's Approach to Technology Diffusion,* NISTIR 6385 (Gaithersburg, MD: National Institute of Standards and Technology, 1999); also see Ruegg, "Assessment of the ATP," 1999.

be slower and less amenable to a deliberate program focus on commercialization of technology by U.S. companies.[66] Nevertheless, ATP can foster the generation of knowledge spillovers by selecting generic technologies applicable to many firms both upstream and downstream and by supporting publishing, patenting, collaborative activities, and other activities through which knowledge is diffused.

The diagram highlights the extension of ATP's role beyond that of technical knowledge generator/disseminator. By engaging the activities of for-profit U.S. firms and requiring them to plan up-front for commercialization and establishment of a pathway to early application of the technology, ATP seeks to meet its mandate to generate accelerated economic benefits and improved competitiveness of U.S. firms in international markets.

Planning Performance Metrics for ATP

An important component of ATP's evaluation program has been to convert the concepts that emerged from modeling its underlying theory into variables amenable to measurement/quantification. In an early effort along these lines, ATP supported the work of Albert Link of the University of North Carolina, Greensboro, to recommend performance metrics for ATP.[67] Link also provided advice on developing an implementation strategy for compiling the metrics.

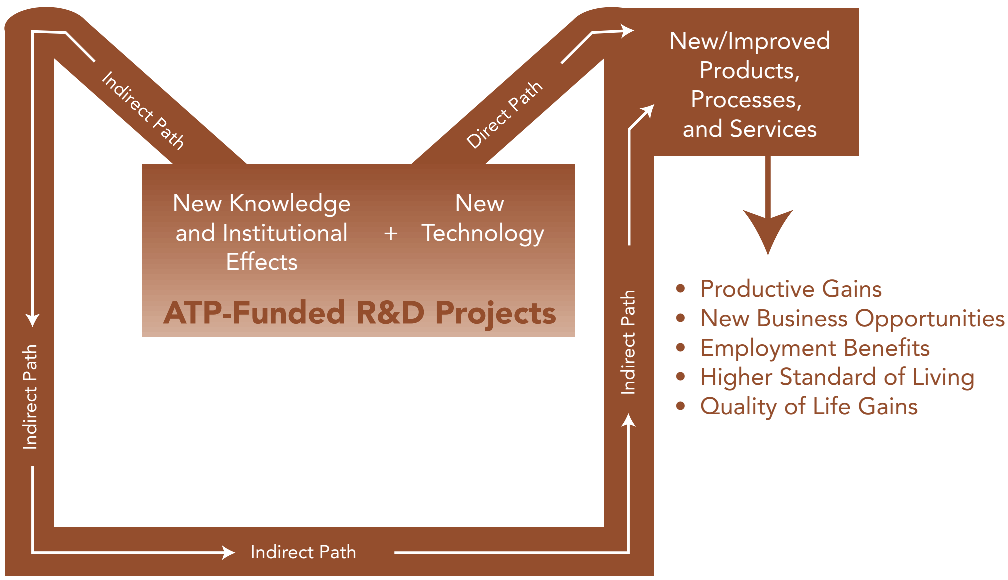
Table 4–4 summarizes Link's recommended set of measures and timetable for collecting them. The nuts-and-bolts data collection plan proved useful for ATP as it sought to implement its evaluation activities quickly. In a very practical way, Link's plan informed the theory and pathways of program effect.

---

[66] R. Ruegg, "Delivering Public Benefits with Private-Sector Efficiency through the Advanced Technology Program." In Charles W. Wessner, ed., *The Advanced Technology Program: Assessing Outcomes* (Washington, DC: National Academy Press, 2000).

[67] Albert N. Link, "Measuring the Economic Impact of the Advanced Technology Program: A Planning Study," unpublished report, 1992.

Figure 4–3. Direct and Indirect Paths to ATP's Impacts



If a project's participating companies successfully take the technology into commercialization (direct path), this is expected to speed the introduction of the technology by U.S. companies. If participants falter in the commercial phase, then they may nevertheless leave behind publications, patents, informed workers, and other means of transferring the knowledge to others who may take it forward. If activities along both paths are successful, then the gains can be even greater, because the social return of the project is the net impact from the combination of the two paths and their interactions.

Source: Ruegg, "Delivering Public Benefits with Private-Sector Efficiency through the Advanced Technology Program," 2000.

Table 4–4. Recommended Metrics for ATP and Timing of Data Collection

WHEN ALL PROPOSALS ARE PROCESSED

- ✓ Number of application kits distributed
- ✓ Number of proposals submitted
- ✓ Number of direct participant research entities represented in submitted proposals
- ✓ Number of proposals disaggregated by sector of applicant, size of applicant, and technology
- ✓ Number of formal research joint ventures formed as part of the proposal process
- ✓ Dollar amount of matching funds committed by applicants
- ✓ Number of re-submitted proposals
- ✓ Percent of non-award applicants from the previous competition receiving a requested debriefing

WHEN AWARDS ARE MADE

- ✓ ATP budget
- ✓ Number of funded projects
- ✓ Dollar amount of applicant resources committed to funded projects
- ✓ Number of funded formal research joint ventures
- ✓ Number of re-submitted proposals receiving awards

WHEN FUNDED RESEARCH PROJECTS ARE UNDERWAY

- ✓ Number of funded projects achieving technical success
- ✓ Number of related patents (applied for/granted) and number of licensing agreements
- ✓ Resources devoted to commercialize products, processes, and services
- ✓ R&D investments related to the funded technology
- ✓ Number of formal research joint ventures formed from new research projects, and the budgets committed to these projects
- ✓ Number of new proposals submitted to ATP
- ✓ Aggregate industry-level R&D investments traceable to the demonstration effect of ATP funding

Source: Link, "Measuring the Economic Impact of the Advanced Technology Program: A Planning Study," 1992, p. 30.

ATP routinely collected much of the data listed in Table 4–4. In the mid-1990s, ATP expanded and revised its data collection efforts to be more responsive to Government Performance and Results Act of 1993 (GPRA) reporting requirements and stakeholder questions.[68]

Understanding Relationships Between Program Design Features and Outcomes

As noted, relationships between program design features and program outcomes are often sketchy. The discovery of systematic differences in the effectiveness of design-feature variations could improve funding decisions. For example, ATP's enabling legislation emphasizes the role of research joint ventures in achieving ATP's mission, but does not suggest which types of partnering arrangements may be most conducive to high levels of program performance. A better understanding of what makes joint ventures work could be useful in guiding ATP's efforts. To this end, ATP supported a study by Jeffrey Dyer, Brigham Young University, and Benjamin Powell, University of Pennsylvania, to investigate factors that increase or decrease the likelihood of success of R&D collaborations.[69, 70]

Dyer and Powell conducted semi-structured interviews with companies participating in 18 ATP-funded joint ventures developing technologies with application in the automotive industry. Their interview discussions centered on the questions listed in Table 4–5.

They found that greater knowledge sharing and more effective coordination among participants characterized the more successful joint ventures. They

68See, for example, U.S. Department of Commerce, Annual Performance Plan, "Science, Technology, and Information Performance Measures for the Advanced Technology Plan." U.S. Department of Commerce, Washington, D.C. An annual performance plan is issued each fiscal year.

69Jeffrey H. Dyer and Benjamin C. Powell, *Determinants of Success in ATP-Sponsored R&D Joint Ventures: A Preliminary Analysis Based on 18 Automobile Manufacturing Projects,* GCR 00–803 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

70To learn more about the workings of joint ventures, ATP also hosted a "lessons-learned" workshop with participants of funded joint ventures at NIST on May 22, 1996. Workshop proceedings are available on-line at ATP's website (http://www.atp.nist.gov/alliance/best_p.htm).

Table 4–5. Interview Questions Investigating Determinants of Success of Joint Ventures

- ✓ How would you define success in a venture like this? What makes one joint venture more successful than another?
- ✓ Is achieving the technical and commercialization objectives proposed to the ATP a good measure of success? Did the joint venture achieve these objectives?
- ✓ What factors influenced the success or failure of the joint venture? What are the barriers to success? What are the enablers?
- ✓ What was the role of the ATP in this joint venture? Did the ATP have any influence beyond the provision of funding?

Source: Dyer and Powell, *Determinants of Success in ATP-Sponsored R&D Joint Ventures: A Preliminary Analysis Based on 18 Automobile Manufacturing Projects,* 2002.

identified several factors that influence the extent to which participants share knowledge, and that influence the costs of coordinating the venture's activities.[71] Their diagram showing the key factors that participants said influenced the degree of success of their joint ventures, the direction and nature of impact, and the linkages from these factors to measures of outcome success is shown in Chapter 9's report on findings, Figure 9–4.

Understanding better how the program contributes to collaborative success and which factors can make or break a joint venture are important for ATP administrators and program managers. For instance, Dyer and Powell documented the importance of face-to-face meetings of participants to build trust, and the critical role of trust in collaborative success. As standard procedure in the contracting process, ATP staff must approve proposed travel budgets for which ATP funds are to be used. So, without an understanding of this underlying success factor, well-meaning staff members could easily make what they intend as "efficient" budgetary decisions (e.g., refusing to approve travel costs for frequent face-to-face meetings among joint venture participants), which may have a negative effect on the project's success.

[71] Because of the relatively small sample size, their findings should be regarded as suggestive and tentative.

Conditioning Expectations through Studies of Private-Sector Behavior

Modeling private-sector decisions and outcomes has helped define expectations of what the program can achieve and helped establish benchmarks for ATP's performance, especially in shaping realistic expectations of the technical and economic successes of a firm's R&D portfolio. Also, of use for ATP has been knowledge about private-sector tools for managing risk, as well as analysis of private-sector decisions in the face of risk, and evolving relationships among firms, universities, and other organizations. A better understanding of barriers to private investment in early stage, science-based innovations sheds light on ATP's value-added role in financing of R&D projects.

Social Rates of Return from Business R&D

Early in its evaluation program, ATP explored the applicability of a widely used model developed in the 1970's by Edwin Mansfield, University of Pennsylvania, to measure market spillovers of R&D.[72] ATP also explored the implications of Mansfield's earlier application of his model to estimate private and social returns from new products or processes when private-sector innovators commercialize their technologies.[73] As Mansfield writes:

> From the point of view of the ATP program, the gap between social and private rates of return from investments in new technology is of central importance. After all, a major rationale for the ATP program is that some R&D projects have social rates of return far in excess of private rates of return. (pp. 26–27)

Mansfield's Model

Mansfield measured resulting market spillovers in terms of "consumer surplus." In Mansfield's approach, the social benefits from an innovation are measured by

72Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities*, NIST GCR 99–780 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

73Edwin J. Mansfield, J. Rapport, A. Romeo, S. Wagner, and G. Be Ardsley, "Social and Private Rates of Return from Industrial Innovation," *Quarterly Journal of Economics* 91(2): 221—240, 1976.

the profits of the innovator from the innovation plus the benefits to consumers following reduction in the price of the good due to the innovation.[74] Figure 4–4 illustrates his basic model.

Mansfield's findings on the characteristics of industrial R&D decision making are drawn from interviews with industrial R&D officials. The interviews point to the difficulty that even the most sophisticated firms have in forecasting the private returns from company-financed R&D projects. Despite the use of and search for formal decision-making models such as scoring systems, programming techniques, and other quantitative decision analysis techniques, "available studies," according to Mansfield, "indicate that few firms, if any, are confident of their forecasts of particular R&D projects."[75] The reasons for this limited ability to accurately forecast rates of return relate to the inherent uncertainties of R&D projects, and to the difficulty that firms have had forecasting development cost and time, the probability of success, and the profitability of new products or processes. According to Mansfield's analysis, firms face an additional difficulty in "forecasting how R&D, if successful, will be utilized."[76] Figure 4–5 illustrates that there is difficulty in trying to forecast private returns from investments in new technology early in the development process, and that the accuracy improves over time. The figure shows the extent of the forecasting errors within a single company for 57 new processes or products as a function of the number of elapsed years after their development. Shortly after the new processes or products were developed, the profit forecasting errors were high. As time passed, estimates of discounted profits were revised each year to the point that they became very close to actual discounted profits. The errors were eliminated through revision over time, but the error rate in the initial estimates was not found to improve over time.

Application of Mansfield's Model to ATP

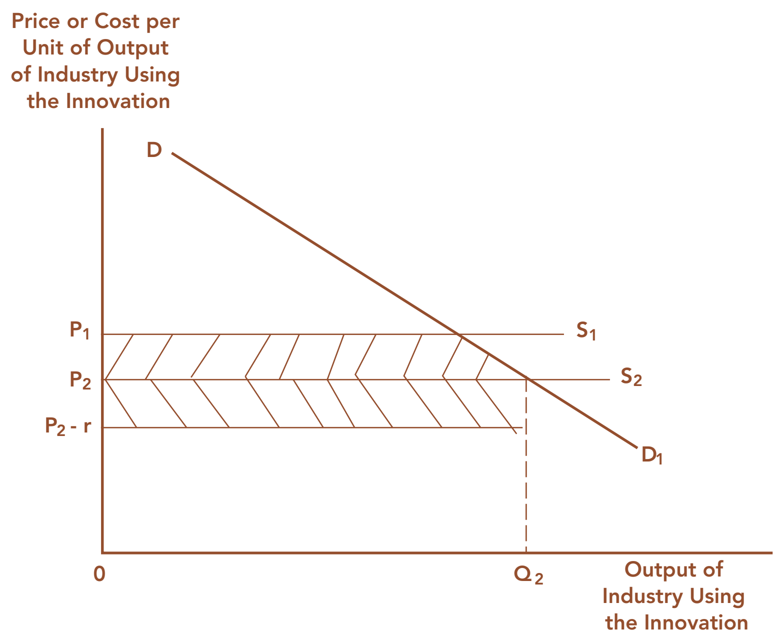
Several factors limit application of Mansfield's model to ATP. Mansfield applied his model to single products, whereas ATP wanted to apply it to technology plat-

[74]Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* 1996, p. 28.

[75]Ibid., p. 2.

[76]Ibid., p. 7.

Figure 4–4. Social Benefits from Product Innovation that Reduces Costs of Industries Using It

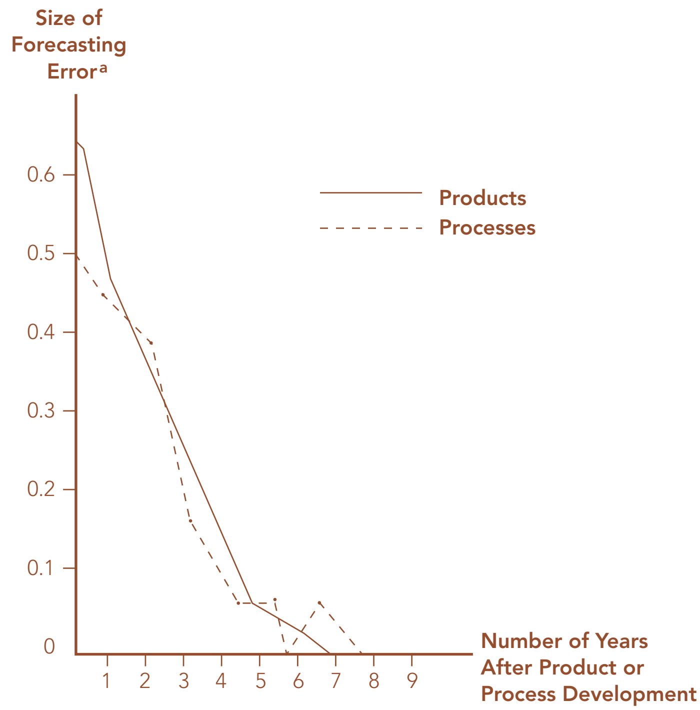


Assume that the supply curve was S1 before the innovation, and the price charged by the industry was P1. After the introduction of the innovation, the supply curve is S2, and the price charged is P2. The social benefits from the innovation are measured as the sum of the two shaded areas shown in Figure 4–4. The top shaded area is the consumer surplus due to the lower price, P2 rather than P1. The bottom-shaded area in Figure 4–4 is an estimate of the additional resource savings from the innovation. A resource savings results, leading to a corresponding increase in output elsewhere in the economy, because the resource costs of producing the good after the innovation are P2 Q2, minus the profits (r) the innovator receives from the innovation. The amount r is merely a transfer from the producers of the good using the innovation to the innovator. On net, there is consumer surplus from the price reduction and a resource savings amounting to the profits of the innovator. (Caveats are given by Mansfield in his report.)

Source: Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* 1996, p. 20.

forms generating multiple products. He used his model to capture only market spillovers, whereas ATP wanted to capture knowledge and network spillovers in addition to market spillovers. Finally, in estimating the model, Mansfield applied his model using many years of historical data, whereas ATP technologies were in the early stages of commercialization.

Figure 4–5. Reducing Inaccuracies in Profitability Estimates Over Time



[a]Computed as the proportion of product/process cases for which the ratio of the profit forecasts made in each successive year after development to actual discounted profits is equal to or greater than 2.0 or less than or equal to 0.5.

Source: Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* 1996, p. 16.

To overcome these limitations, Mansfield recommended applying his model multiple times to capture market spillovers of enabling technologies with multiple applications. To meet concerns about the large forecasting errors early in the life of a new product and the fact that these errors tend to diminish rapidly as time passes, Mansfield recommended repeating and updating a set of case studies several times to see how the results changed over time. The commissioned a set of cases with Mansfield to be done according to his recommendations, recognizing that supplemental techniques would be needed to capture knowledge spillovers omitted from Mansfield's model.[77]

Other case studies of ATP projects have followed Mansfield's basic approach. See, for example, the calculation of social and private rates of return on medical technologies performed by Research Triangle Institute, discussed in Chapter 6.

Implications of Mansfield's Model for ATP

Mansfield's model provided a starting point for modeling the social and private rates of return of ATP-funded projects, and the empirical results from his work provided an initial benchmark for ATP's assessment of the effects of its awards. Mansfield's work, conducted in the late 1970s, included estimates of the private and social rates of return of 17 private-sector innovations. In this study he collected data on project costs, revenues, and profits. He then collected similar data from other firms in the same industry for similar products and processes they introduced, data from firms purchasing or licensing the new products or processes, and data from final users of consumer goods. From these data he calculated the private and social rates of return on the innovations. Of particular interest to ATP, Mansfield found significant market spillover benefits to consumers, even when the private returns were low or negative.

The results became well known among economists, and have conditioned general expectation about the relationship between social and private rates of returns from technological innovations. The results, in effect, "up the ante" for ATP; funding projects that yield positive market spillovers would not be sufficient for program success because "routine" private-sector innovation could do that. The existence of positive market spillovers from private-sector innovation underlies Jaffe's observation, as noted above, that ATP would have to fund projects that yield higher-than-normal spillover effects if it were to add value as a public-sector program. This observation had important programmatic implications for ATP, because it led to a search for innovative projects with the potential to create substantial social benefits while meeting private-sector criteria necessary to gain participation by private firms.

[77]Mansfield's death unfortunately ended the project.

Adequacy of Private Investment

The 1980s and 1990s saw a substantial increase in venture capital funds and investment funds available from "angel" investors. The larger amounts of venture funds were largely the result of a change in law that no longer prohibited institutional investors from venture investing.[78] The larger amounts of angel funding were attributable in part to the dramatic increase in personal wealth in the United States over the same period. Table 4–6 traces the amount of venture capital raised each year from 1977 through 1995, as well as the amount of venture funding going to early stage investments. Nearly three times as much went to early stage investments in 1995 as in 1977, though at the time of preparing this report there has been a cyclical contraction in venture funding.

The increase in private sector supply of venture capital funding was one of the facts cited to challenge the need for government funding of high-risk technological innovations, and thus ATP. To explore this issue, ATP commissioned an inquiry into the supply of venture capital to fund enabling, high-risk technologies.

Paul Gompers and Josh Lerner, both professors at Harvard University Business School and members of the NBER, conducted the study, investigating the trends and patterns of venture capital and angel funding available to small innovative firms.[79] Gompers and Lerner also conducted seven case studies of small R&D-intensive firms funded by ATP to determine why those firms needed ATP funding and the role the funding played. Several of their findings help to explain why, despite the large increase in private venture funds, projects of the type targeted by ATP can go wanting.[80]

Putting the supply of venture capital in perspective, the researchers found that despite the increases in venture capital supply, less than one tenth of 1% of

---

[78]Paul Gompers and Josh Lerner, *Capital Formation and Investment in Venture Markets: Implications for the Advanced Technology Program,* NIST GCR 99–784 (Gaithersburg, MD: National Institute of Standards and Technology, 1999).

[79]Ibid.

[80]The authors' focus was on financing of companies and not on the enabling nature of the technologies, that is, underinvestment owing to spillovers was largely outside the study's sphere. "Early-stage" was used as a proxy for the type of projects of interest to ATP. It captures one aspect of ATP projects but is not necessarily synonymous with funding high-risk, enabling technologies.

Table 4–6. Volume of Venture Capital Activity

AMOUNT OF VENTURE ACTIVITY

Year	Venture capital (Raised in year, millions of 1994 dollars)	Early-stage investments by venture funds ($ millions of financings in 1994 dollars)	Number of financings
1977	91	474	N/A
1978	442	520	N/A
1979	503	755	N/A
1980	1260	802	N/A
1981	1713	806	227
1982	2061	813	343
1983	5516	1707	413
1984	4931	1689	568
1985	4240	1194	529
1986	4429	1478	716
1987	5550	1440	796
1988	3822	1272	674
1989	3858	1119	623
1990	2173	705	571
1991	1569	458	335
1992	2822	646	435
1993	3008	765	368
1994	4596	1005	499
1995	4536	1438	611

N/A = Data not available.

business startups annually have received venture financing in recent years. They described lemming-like behavior on the part of many venture capitalists, leading to a concentration of investments in “hot” technical areas, while other areas attract little or no venture capital. They identified geographical concentration of the bulk of the venture capital, noting that companies in many parts of the nation receive little or no venture capital. They suggested that the shift in the source of

Table 4–6. (Cont'd)

LEADING STATES, VENTURE FINANCING, 1995

State	$Millions of financings	Percent of total	Number of financings
California	2274	30.6	437
Massachusetts	772	10.4	131
New Jersey	724	9.7	36
Texas	352	4.7	40
Illinois	340	4.6	29

LEADING INDUSTRIES, VENTURE FINANCING, 1995

Industry (SIC code)	$Millions of financings	Percent of total	Number of financings
Communications and networking	1376	18.5	180
Software and information services	1239	16.7	291
Retailing and consumer products	1207	16.2	90
Medical compounds	716	9.6	113
Medical devices and equipment	607	8.2	108

Source: Gompers and Lerner, *Capital Formation and Investment in Venture Markets: Implications for the Advanced Technology Program,* 1999, p. 17.

venture capital away from the individual investor and toward the institutional investor means that there is a greater preference for less risky R&D and shorter time horizons for realizing returns on these investments. They suggested that investors, for management purposes, have tended to increase the size of individual investments, rather than increase the number of investments in proportion to the growth of funds available. Hence, a doubling in the amount of venture funds available does not result in a doubling in the number of projects funded, but rather an increase in the size of the average project, as a fund manager can better stretch limited managerial resources over a portfolio with a higher dollar value than one that contains more projects. From their case studies, described further in Chapter 6, the authors concluded that each of the companies examined struggled to obtain funding to undertake its innovative research and was unable to secure sufficient funding from private sources.

Private Firm R&D Decisions in the Face of Risk

To define the role technical risk plays in the financing decisions of firms and to explore further the adequacy of funding for developing high-risk, enabling technologies, ATP commissioned Harvard's John F. Kennedy School of Government, in collaboration with MIT's Sloan School of Management and the Harvard Business School, to conduct a broad ranging study.[81] The Harvard-MIT Project on Managing Technical Risk examined barriers to private investment in early-stage, high-risk technology development projects. The study's objective was to assist ATP to "better identify projects that would not be pursued or would be pursued less vigorously without ATP support and at the same time are likely to lead to commercial success—with broad public benefits—with that support."[82]

The Harvard-MIT study drew primarily on expert assessments offered by industrial, academic, financial, and government representatives participating in a series of workshops held between 1999 and 2001. The workshops were organized around discussions based on a set of papers commissioned by academic participants and practitioners.

The study, in part, updated Mansfield's summary of the techniques, behaviors, and perceptions of R&D managers toward technical and economic risk. The Harvard-MIT project examined the institutional, behavioral, financial, and non-financial barriers that produced inadequate incentives for entrepreneurs, venture capitalists, and corporations "to undertake some varieties of early-stage, high-risk technology development projects that have potential to generate radically new products and processes."[83]

[81] L. M. Branscomb, Kenneth P. Morse, and Michael J. Roberts, *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-Based Project,* NIST GCR 00–787 (Gaithersburg, MD: National Institute of Standards and Technology, 2000). This study provided the basis for the subsequent publishing of L. M. Branscomb and Philip E. Auerswald, *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks* (Cambridge, MA: MIT Press, 2001).

[82] Branscomb et al., *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-Based Project,* 2000, p. 3.

Managing Risk

Several themes about risk and its effect on financing technology emerged from the Harvard-MIT workshops. Industry R&D participants emphasized the art of quantifying technical risk. Further, although participants noted the existence of numerous well-established methodologies for assessing technical risk, their consensus was that none of these methods was very successful.[84] Still, they agreed that understanding the sources of risk and dealing with them systematically is important.

Participants expressed varying perspectives on the ability to separate technical risk from market risk. As posed by the project's report, "In a radical technical innovation, can one expect to define product and process specifications, then engage in research that is sufficient to reduce technical uncertainties to an acceptable level?"[85]

The problem here, as described by several industrial representatives, is that the desired market "specifications" about the characteristics of the intended product can be unstable. Consumer requirements may change during the project. Independently, the performance of the technology may evolve differently than predicted. "Those differences require an adjustment in the specifications, which in turn requires that market estimates be adjusted, which in turn may suggest a further adjustment in product specifications."[86]

Institutional Factors

As part of the Harvard-MIT study, a commissioned paper by Scott Shane, University of Maryland, tested the proposition that newly created firms are "a particularly appropriate institutional form within which to make success of radical, science-based innovations,"[87] while a commissioned paper by

[83]Ibid., p. 1.
[84]Ibid., p. 8.
[85]Ibid., p. 15.
[86]Ibid., p. 16.
[87]Ibid., p. 23.

James McGroddy found that "a large firm with deep technical roots has some advantages over the startup with limited resources, in that the former can incubate the technology for several years before bringing it to market, thus reducing substantially the uncertainties surrounding the technical challenges."[88] Generally, the Harvard-MIT study highlighted an increased inter-firm and inter-sector dependence of purchasers and suppliers of both R&D and goods on one another.

The findings and assessments presented in the Harvard-MIT study suggest that the process of commercializing promising technical concepts involves more than public sector funding of pre-commercial R&D. Rather, "institutional" factors as much as "economic" factors may hinder private investment in early stage, science-based innovations. This finding poses new questions and program design issues for ATP. Thus, according to the study:

> ...major changes are transforming the institutional structure of the high-tech industrial economy. Large corporations are increasingly focusing on their role as system integrators, low-cost producers, and distributors and marketers internationally, while outsourcing much of their innovation to mid-size and smaller, technically specialized firms in their supply chain. Where will those small-to-medium size firms get their insights into the art of the possible from new science, if not from the large firms they serve? Is this another reason for public programs like ATP? (p. 6)

"Valley of Death"

The Harvard-MIT study also addressed the adequacy of private-sector funding of high-risk R&D projects. Whereas the Gompers-Lerner study addressed the overall availability of venture capital, the Harvard-MIT study cited a striking degree of general agreement among technical entrepreneurs, high-tech business managers, and venture capital investors about the existence of a "Valley of Death"—a significant gap between federally funded basic research and industry-funded applied research and development.

[88] Ibid., p. 22.

According to the Harvard-MIT study:[89]

> Congress appears to have intended the ATP to be a mechanism for addressing the "Valley of Death" area of research, which has been described by Charles Vest, president of MIT, as "mid-level" research, and by Branscomb as "basic technology research."
>
> If such a gap is real, the fact that growth of commercial R&D is outstripping the growth of government-funded [R&D] only means that the gap may be growing, not shrinking, as public funding of early stage research fails to keep pace with commercial development. (p. 49)

Positioning ATP in Capital Markets

There are a number of federal programs that provide grants, loans, and other forms of assistance to U.S. firms. One of the challenges of a program like ATP is to convey how it differs from other programs and the circumstances under which it is a suitable or unsuitable funding source for a given organization. This communication necessarily takes place with busy CEOs, CFOs, and company researchers against a cacophony of background noise. Clarity is critical.

Figure 4–6 reproduces a framework that locates ATP in the broader financing landscape.[90] It is part of a planning guide prepared for use by ATP award recipients in the post-award period, but it also serves as a broader outreach tool for ATP.

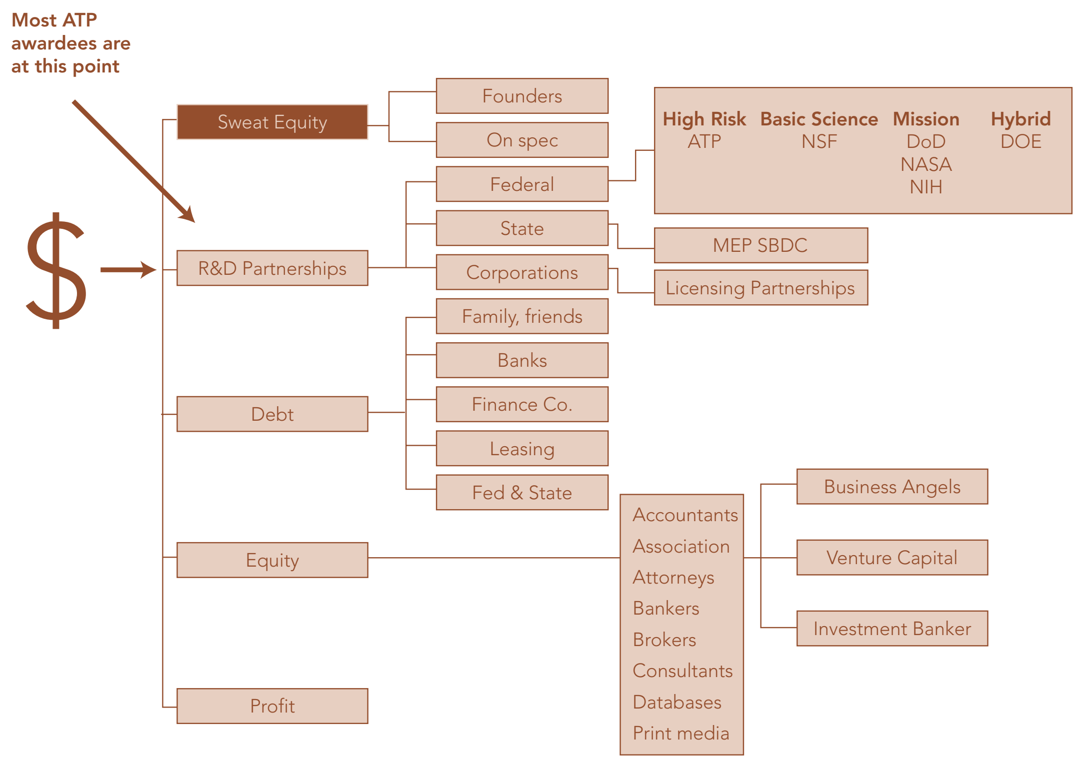
The guide, an important tool of communication with ATP's direct stakeholders, models complex business strategies for the technology platforms envisioned as downstream results of the R&D projects. Figure 4–7 illustrates ATP's goal to foster creation of technology platforms that can spawn multiple business opportunities. The guide also covers teaming arrangements, and many other concepts critical to the awardees achieving not only business success, but also project success.

---

[89] Branscomb et al., *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-Based Project,* 2000.

[90] Jenny C. Servo, Dawnbreaker Press,© *Commercialization and Business Planning Guide for the Post-Award Period,* NIST GCR–99–779 (Gaithersburg, MD: National Institute of Standards and Technology, 2000).

Figure 4–6. Roadmap of Financing Options

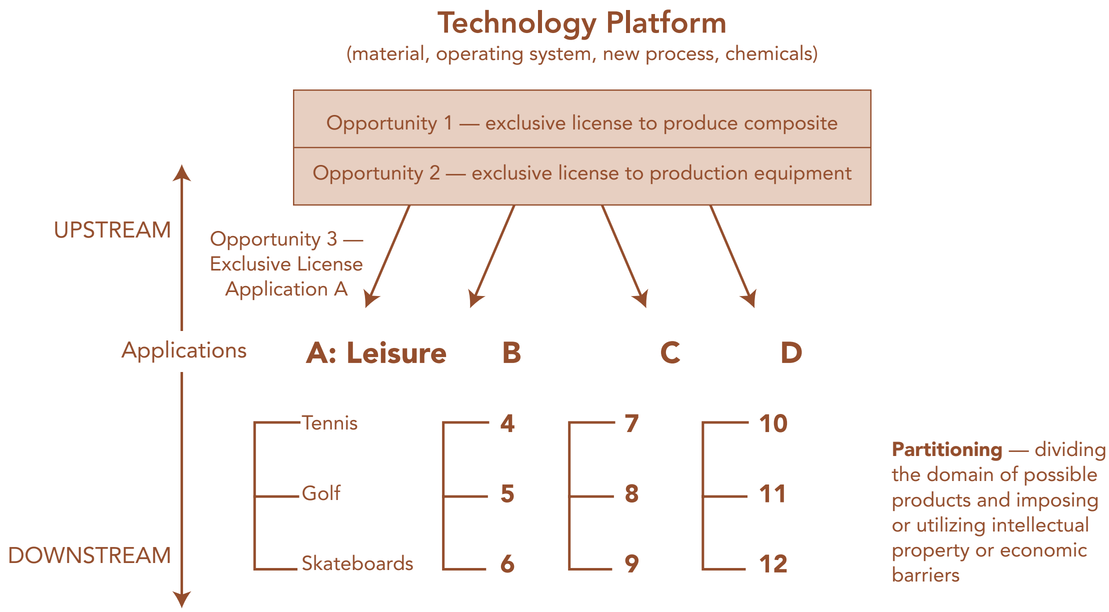


The figure shows five categories of financing in a financing roadmap. As indicated by the arrow and side note, ATP awardees are seeking an R&D partnership. Federal, state, and private sources provide financing opportunities through partnerships. The figure distinguishes ATP's role from the other partnership opportunities.

The figure also points to alternative sources of financing that award recipients can attempt to access as the ATP funding is drawn down. The Commercialization and Business Planning Guide positions ATP in the financing landscape and assists startup companies who need help with the ins and outs of seeking and obtaining financing from different sources.

Source: Servo, *Commercialization and Business Planning Guide for the Post-Award Period,* 2000, p. 20.

Figure 4–7. Strategic Mind Map for a Rich Technology Platform



The figure shows an example of a company that has developed a portfolio of intellectual property to protect its process for creating a new material as well as the devices used to produce the material. The figure illustrates partitioning of multifaceted opportunities, taking into account downstream and upstream potential applications, intellectual property positioning, and economic factors. It shows multiple licensing opportunities (i.e., to license a process to produce material, to license production equipment, and to license in application-specific product market) and multiple application areas.

Source: Servo, *Commercialization and Business Planning Guide for the Post-Award Period,* 2000, p. 53.

Conditioning Expectations through Studies of Other Public Sector Programs

With new programs come new expectations, and defining reasonable expectations is critical to a new program's success. Examining state programs and counterpart programs abroad has helped condition general expectations about ATP.

Interface of ATP with State Programs

In the United States, the same macroeconomic and international economic trends that gave rise to the establishment of ATP also led to a rethinking by state governments of how best to promote state economic development. Many states began taking more active steps to revitalize their economies.[92] This led to a modest shift in emphasis from traditional state recruitment strategies that centered on bidding for existing firms through monetary incentives, such as reduced taxes, to one on generating new firms and industries.[91]

Beginning in the early 1980s, a growing number of states established state technology programs. Varying somewhat in emphasis across the basic research, applied research, and commercialization continuum, these programs included a diverse set of specific programs: incubators, venture capital funds, manufacturing modernization programs, cooperative university-industry R&D programs catalyzed and subsidized by state funds, and others.[93]

The parallel development of state and federal government technology programs throughout the 1980s created new opportunities as well as complexities in coordination. Several of the major federal initiatives, such as the National Institute of Standards and Technology's Manufacturing Extension Partnership program and the National Science Foundation's Engineering Research Centers program, required state contributions, but ATP did not. Consequently, few direct linkages existed at the outset between ATP and the state programs.

To examine the relevance of state technology development programs to its operations, ATP commissioned a two-volume study of state experiences, under the title, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* Volume 1: *A Guide to State Business Assistance Programs for New Technology Creation and Commercialization,* is authored by Marsha

[91]Scott Fosler, *New Economic Role of the States* (New York: Oxford University Press, 1988).

[92]Peter Eisinger, *The Rise of the Entrepreneurial State* (Madison, WI: University of Wisconsin Press, 1988); Irwin Feller, "American State Governments as Models for National Science Policy," *Journal of Policy Analysis and Management* 11:288–309, 1992.

[93]Dan Berglund and Christopher Coburn, *Partnerships: A Compendium of State and Federal Cooperative Technology Programs* (Columbus, OH: Battelle Press, 1995).

Schachtel, a Senior Fellow at the Johns Hopkins Institute for Policy Studies, and Maryann Feldman, then Associate Professor of Economics at Johns Hopkins University and Director of its Information Security Institute, and now a professor in the Rotman School of Management at the University of Toronto. Volume 2, *Case Studies of Technology Pioneering Startup Companies and Their Use of State and Federal Programs,* is authored by Maryann Feldman, Maryellen Kelley, then of ATP and later of Pamet Hill Associates, Joshua Schaff, Director of the New York City Democracy Network, and Gabriel Farkas, graduate student at Dartmouth College. The second volume presented four case studies describing how ATP award winners used state government programs in combination with ATP assistance. It is discussed in greater detail in Chapter 6.[94]

Volume 1 analyzed the structure of the state programs, and thus provides a benchmark against which both the distinctive and complementary roles of ATP can be examined. It described the range of state services available both to applicants and awardees, such as guided access to technical information, patent search assistance, technical assistance from university and extension agents, and others, along with examples of specific state programs. Of direct relevance to ATP's evaluation efforts was the report's delineation of the challenges that underlay efforts by the private sector to commercialize technology, and of the place of state government, and implicitly, federal government efforts in assisting private firms. Volume 1 serves as a guide to award recipients to "the type of state resources available to help them carry out the commercialization plans outlined in their project proposal, grow their businesses, and eventually successfully diffuse the technologies developed with ATP's financial assistance."[95]

[94]Marsha R.B. Schachtel and Maryann P. Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* vol. I, *A Guide to State Business Assistance Programs for New Technology Creation and Commercialization,* NIST GCR 00–788 (Gaithersburg, MD: National Institute of Standards and Technology, 2000); and Maryann P. Feldman, Maryellen R. Kelley, Joshua Schaff, and Gabriel Farkas, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* vol. 2, *Case Studies of Technology Pioneering Startup Companies and Their Use of State and Federal Programs,* NISTIR 6523 (Gaithersburg, MD: National Institute of Standards and Technology, 2000).

[95]Schachtel and Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* 2000, p. 1.

The framework provided in Table 4–7 helped define the scope of ATP's involvement in the multiple aspects of developing and commercializing technological innovations relative to the scope of involvement by the states. This definition of what ATP is and what it is not, is a necessary element in specifying the criteria against which the program is to be evaluated. By identifying the range and content of the panoply of state technology programs available to ATP applicants and awardees, the Schachtel-Feldman study pointed to the presence of complementary variables linking ATP support to specific outcomes. In effect, for some set of awardees the impacts of ATP grants are moderated by whether or not they receive supplemental state support in any of the nine cells described above. This statement leads to a previously unidentified evaluation question: Do ATP awardees who receive support from state technology programs generate different technical or economic outcomes than those firms which did not receive such supplemental assistance? This unanswered question has implications for the ways in which ATP seeks to couple its activities with those of state programs.

Comparisons of ATP with Counterpart Programs Abroad

ATP was established after a number of similar programs in other industrialized countries were up and running. According to three notable economists, Zvi Griliches, Haim Regev, and Manuel Trajtenberg:[96]

> Most OECD [Organization for Economic Cooperation and Development] countries have government-funded R&D support programs that encourage private investment in civilian R&D. There seems to be a rather wide consensus among economists in the OECD countries that the social rate of return to R&D investment substantially exceeds the private rate of return, suggesting that government action to promote research and development enhances economic welfare. (p. 2)

ATP's interest in counterpart programs in other countries was motivated by two objectives: to learn from these programs in order to make ATP a better program

[96]Zvi Griliches, Haim Regev, and Manuel Trajtenberg, *R&D Policy in Israel: Overview and Lessons for the ATP,* Draft report, ATP, 2000.

Table 4–7. Categorizing State Technology Assistance Program by Type of Challenge and Stage of Technology Development and Commercialization

	CONCEPT PHASE	DEVELOPMENT PHASE	COMMERCIALIZATION PHASE
Technical challenges	✓ Schematic or design of main features of technical concept ✓ Patent search	✓ Working model ✓ Engineering prototype ✓ Pre-production prototype	✓ Market-ready manufactured product ✓ Related technology spinoffs ✓ Continuous production improvement
Market challenges	✓ Initial market assessment pricing structure ✓ Identification of market barriers and risks	✓ Marketing section of the business plan ✓ Initial sales ✓ Review of customer response	✓ Analysis of sales performance and customer response ✓ Diversification to a portfolio of products
Business challenges	✓ Venture assessment to determine whether there is profit potential ✓ Identification of sources of financial and human resources ✓ Intellectual property protected	✓ Conceptual plan with some or more financial scenarios ✓ Final business plan ✓ Acquisition of seed capital ✓ Business launch	✓ Acquisition of equipment and facilities ✓ Hiring and training of personnel ✓ Next stage financing ✓ Continuous business improvement

This framework is derived from Randall Goldsmith's model of product commercialization. Analytically, each cell in the framework corresponds to a specific possible combination of private sector-public sector (state/federal) relationships. The framework provides Schachtel and Feldman a means of organizing descriptions of the diverse set of state technology development programs in place by the late 1990s.

Their use of the Goldsmith model also has more expansive purposes. It helps describe and implicitly delimit the relative areas of R&D emphasis of ATP and state government programs. State technology programs span the R&D continuum from support of basic research and human capital development via grants to university faculty for research and support of graduate students (e.g., Texas), through support of generic/precompetitive research (e.g., Ohio and New Jersey), to an emphasis on spawning spin-off firms and product development (e.g., Connecticut and Pennsylvania), with some states having some of all of the above. Collectively then, an account of state programs is likely to fill up the Goldsmith cells. The ATP, by way of contrast, has centered its activities on technical challenges, supporting work primarily in the concept and development phases—just two of the nine boxes in the Goldsmith framework.

Source: Schachtel and Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* 2000, p. 3. Matrix adapted from H. Randall Goldsmith, "A Model for Product Commercialization," Oklahoma Alliance for Manufacturing Excellence, Tulsa, OK, 1995.

and to implement a statutory requirement pertaining in part to foreign counterpart programs. The requirement is that ATP include in its funding consideration the participation of U.S.-based subsidiaries of foreign-owned companies only if their participation passes three additional tests beyond the selection criteria to which all proposals are subject. One of the tests is that "the parent company is incorporated in a country which affords to United States-owned companies opportunities comparable to those afforded to any other company, to participate in any joint venture similar to those authorized under this chapter…."[97] To apply this provision requires that ATP keep abreast of counterpart programs in other nations and to apply the country-specific provisions to determine eligibility whenever a proposal from a foreign-owned subsidiary reaches the semifinalist stage in an ATP competition.[98]

ATP's interest in comparative programs gave rise to analytical studies, briefings and exchanges with foreign visitors, and participation in international conferences and forums. Although not described here in detail, conferences provide productive opportunities for ATP staff to review program and operational features with their counterparts in other countries.

A Common Lexicon and Framework for Making Comparisons

While many external similarities exist between ATP and the technology support programs of other countries, differences also exist. Direct comparisons that do not account for these differences are of limited value in learning about performance. To address this problem and to improve understanding of how these programs operate, ATP economist Connie Chang developed a lexicon for discussing program design features and analyzing their structures. She then applied the lexicon to a sample of ATP-like programs abroad and

[97]Sec. 278n, (9)(A & B), P.L. 100–418, amended by P.L. 102–245.

[98]All proposals must meet the test of being in the national interest of the United States. The additional provisions to which foreign-owned, U.S.-based subsidiaries are subject, beyond the one listed in the text, are: "that the country affords United States-owned companies local investment opportunities comparable to those afforded to any other company; and affords adequate and effective protection for the intellectual property rights of United States-owned companies." The "finding of foreign eligibility" has been delegated from the Secretary of Commerce to the Director of the Advanced Technology Program.

to a sample of their features. These findings are illustrated in Chapter 9, Table 9–21.[99]

Chang's work provided a systematic protocol that permits ATP and others to compare similar yet diverse international public-private partnership programs for advanced technology development across their salient features. Features of particular interest included program eligibility requirements, the nature of funded research, technical scope, the selection process, and public-private financial arrangements.

As Chang expressed it:

> 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. (p. 10)

If one country's program succeeds and another fails, then that success may reflect their differences rather than their similarities.

International Programs

Another view of programs abroad and their comparison with ATP was provided by proceedings of an international conference on evaluation hosted by ATP in 1998.[100] Bringing together evaluators from around the world, the conference had the theme of economic evaluation of science and technology programs in industrial countries. Fifty abstracts were submitted from government agencies and academic institutions from around the world, including France, Germany, Italy, Switzerland, Norway, Australia, Romania, Israel, the European Union, and China. Five abstracts describing programs similar to ATP were selected for full paper development and presentation at the conference—papers from Switzerland,

[99]See Connie K.N. Chang, "A New Lexicon and Framework for Analyzing the Internal Structures of the U.S. Advanced Technology Program and its Analogues Around the World," *Journal of Technology Transfer*, 23(2): 67—73, 1998.

[100]Richard N. Spivack, ed., *Proceedings of an International Conference on the Economic Evaluation of Technological Change,* NIST Special Publication 952 (Gaithersburg, MD: National Institute of Standards and Technology, 2001.) The conference co-chairs were Richard Spivack, ATP, and Lee Branstetter, then at University of California, Davis, and now at Columbia Business School and the NBER (National Bureau of Economic Research).

Germany, Norway, the European Union, and Israel. Five additional evaluation methodology papers were selected that were commissioned by ATP.

Differences in evaluation methodologies were readily apparent in these papers. As noted by Dr. Phillipe Laredo of the Centre de Sociologies de l'Innovation, France, nearly all the U.S. conference papers emphasized the importance of spillovers while references to spillovers were completely absent from presentations from other countries. According to Laredo: "The former focuses more on producing figures (what return for the public investment) while the latter insists more on images (what changes in the innovation landscape). They might well be two corners of the same story...."[101, 102]

Testing ATP Models with Data from Other Programs

Several models developed for use by ATP were tested with data from other programs that had a longer history of operation. The results of those tests not only demonstrated the workings of the models, but also conditioned expectations about possible findings when the models could be applied to ATP data.

Using Japanese Data to Pilot Test an Analytical Framework

Mariko Sakakibara, University of California, Los Angeles, and Lee Branstetter, Columbia Business School and the NBER (National Bureau of Economic Research), developed a framework to measure the economic impact of ATP-funded research

[101]Philippe Laredo, Comments, in Richard N. Spivack, ed., *Proceedings of an International Conference on the Economic Evaluation of Technological Change*, NIST Special Publication 952 (Gaithersburg, MD: National Institute of Standards and Technology, 2001) pp. 158–159.

[102]These differences in evaluation methodology have been noted by both U.S. and European evaluators and policy makers for a number of national R&D programs, not only those closely related to ATP. Differences in approaches to evaluation reflect differences in the political, economic, and academic environment, and differences in the way evaluation is organized in the various countries. As expressed by Feller, describing the relatively more decentralized character of the U.S. evaluation system, "Multiple sponsors fund multiple researchers located in multiple institutions; the result is a diverse, at times competitive evaluation marketplace, in keeping with the characteristics of the U.S. political and academic systems. Methodological orthodoxy, thankfully, is impossible to establish." (Irwin Feller, "The Academic Policy Analyst as Reporter: The Who, What, and How of Evaluating Science and Technology Programs," in Philip Shapira and S. Kuhlman, eds., *Learning from Science and Technology Policy* Evaluation (London: Edward Elgar, 2001)).

consortia using patent data.[103] While they were able to work with U.S. patent data to some extent, they also used Japanese data as a statistical "testing ground."

According to the researchers:

> Japanese Government involvement in publicly supported research consortia dates back to the late 1950's; examining this data will enable us to observe the long-run impact of consortia on patenting outcomes. (p. 27)

They further noted:

> Results from Japanese data indicate that the effect of consortia on patenting outcomes tends to persist for relatively long periods of time. In fact, patenting in the targeted area seems to increase a bit after the cessation of the consortium, before leveling off again in later years. ... For our purposes, the important point to keep in mind is that the effect of consortia can be quite long lasting. This suggests that our estimates of the impact of ATP-funded consortia, based on only four years of data, may underestimate the total impact of research consortia on patenting outcomes of the firms that were involved. (p. 28)

Using Israeli Data to Demonstrate Productivity Measurement

Zvi Griliches of Harvard University and NBER, in collaboration with Manual Trajtenberg of Tel Aviv University and NBER, and Haim Regev of Israel's Central Bureau of Statistics developed an econometric approach to estimate the productivity impacts of ATP on private firms receiving funding.[104] But ATP's history was not sufficiently long to allow application of the model. To demonstrate their approach, the researchers investigated data requirements and tested the model with Israeli data from ATP counterpart programs. Their work is covered in more detail in Chapters 4 and 7.

[103] Mariko Sakakibara and Lee Branstetter, *Measuring the Impact of ATP-Funded Research Consortia on Research Productivity of Participating Firms: A Framework Using Both U.S. and Japanese Data,* NIST GCR 02–830 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

[104] Griliches et al., *R&D Policy in Israel: Overview and Lessons for the ATP,* Draft report, ATP, 2000.

Conditioning Expectations About Program Time Horizons

Stakeholder requests for empirically based measures of program impact soon after ATP began alerted program administrators that they needed to condition expectations about the timing of outputs, outcomes, and impacts. They needed to communicate that ATP's larger benefits will take time; that technology creation, commercialization, and broad diffusion is a lengthy process. But they also needed to be more specific than simply stating that more time is required.

The question of appropriate time horizons affects not only evaluation but also project selection. When is a project too short term or too long term to fit ATP? This particular question was of keen interest to ATP. The notion that a project can have a too-short time horizon stems from an assumption that difficult technical problems will take time to solve. So, a too-short time horizon may mean that "low hanging fruit" projects—projects pursuing low risk technologies—have been selected for awards, undercutting a rationale for the program. On the other hand, a project whose anticipated benefits lie a number of decades in the future are deemed at too early a stage for ATP, because of the program's emphasis on producing economic benefits through accelerated development and commercialization of technology.

Conceptual Time Path

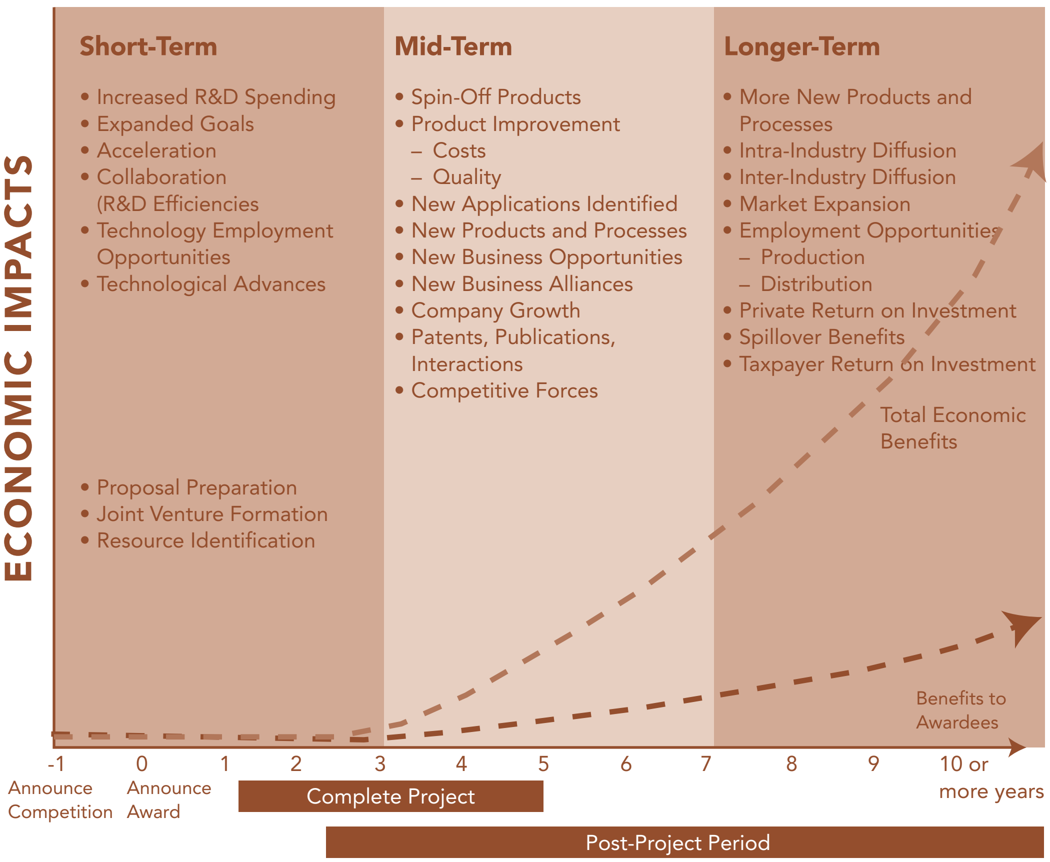
Figure 4–8 shows a conceptual depiction of ATP's time path that ATP staff has used to condition expectations about the program's time horizon. The figure also lists the type of effects anticipated at each stage, conditioning expectations about what can be measured by evaluation efforts at different stages.

Timeline Examples

In 1999, William Long, a consultant in economics affiliated with NBER—and assisted by ATP staff—documented the specific time paths for two of the first 38 completed ATP projects.[105] One of the projects was in biotechnology, and the

[105]William F. Long, *Performance of Completed Projects,* Status Report 1, NIST Special Publication 950–1 (Gaithersburg, MD: National Institute of Standards and Technology, 1999), pp. 5–7.

Figure 4–8. Conceptual Time Path for ATP's Technology Diffusion and Expected Impacts



Economic impacts are depicted on the vertical scale and time on the horizontal scale. The lower curve, "benefits to awardees," shows returns to the project innovators increasing over time as they commercialize or license their technology. The upper curve, "total economic benefits," shows returns to the economy at large increasing as the technology diffuses into wider use and generates spillovers. The conceptual benefits curve starts above zero at the time of competition announcement, implying that there will be benefits from the technology project planning and formation of collaborations stimulated by the announcement. The "total economics benefits" curve is drawn more steeply as it begins to separate from the "benefits to awardees" curve toward the project end, signifying an expectation of increasing spillover benefits over time.

Source: Ruegg, "Assessment of the ATP," 1999, p. 19.

other was in computer software. Long found many of the same activities occurring in both timelines, but at very different times. The biotechnology project, which involved development of a medical technology as an outgrowth of university research, required a lengthy path of regulatory approval. In contrast, the software developer was able to enter into licensing agreements with other companies near the end of the project, and therefore, the timeline from research to commercialization was compressed.

The fact that both of these projects took on significant technical challenges, essentially stayed on their respective but different tracks, and met ATP's expectations implied that there is considerable variation in acceptable time horizons among successful projects. The type of technology appeared to play a major role in the time required for commercialization and diffusion, as well as other factors such as business strategy, financing, regulatory requirements, and demand factors. These examples conditioned stakeholders to expect variation in timing among projects, even as the model shown in Figure 4–9 continued to provide general guidance.[106]

Testing Dominant Paradigms

Modeling underlying program theory helps administrators check the applicability of mainstream propositions before setting out on an evaluation design built upon those propositions. The abundance of existing theories and models can be deceptive, leading to uncritical acceptance of analytical assumptions and paradigms that do not fit. As understood by ATP, this caution does not lead to a rejection of mainstream approaches; rather it serves as a reminder to avoid premature analytical or methodological closure by quickly settling for dominant paradigms.

Productivity Impacts on Private Firms in Public Partnership Programs

Among the influences conditioning negative expectations about ATP's impacts were previous studies of the impacts of government defense- and space-related R&D on firm productivity. Some of these studies suggested that the economic

[106]More recently, ATP's Business Reporting System survey data have provided more empirical data on timelines and how they differ among technologies. See Jeanne Powell and Francisco Moris, *Different Timelines for Different Technologies,* NISTIR 6917 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

impact of government-funded research is lower than on private research or largely negative.[107] The lower productivity of the defense side of large companies serving government defense and commercial markets has been put forward to support this proposition.

The question of whether government funding of private companies has an unavoidable depressing effect on the productivity of the firm's R&D is important in determining the "net" impact of ATP's support of private sector R&D activities. Formulation of the problem clearly relates to a central issue surrounding ATP's operations: that is, whether the program affects the productivity as well as the total amount of R&D conducted by ATP awardees.

To test the feasibility of econometric estimation of productivity impacts on firms, Griliches, Trajtenberg, and Regev turned to Israeli counterpart programs as noted earlier.[108] Israel, with its approximately 20 years of experience in wide-ranging efforts to develop and promote its high technology sectors, provided a test bed for assessing the productivity impacts of government support of private sector R&D.

Findings based on application of their model indicated that for the full period covered in the study, 1975–1994, government-supported R&D was "*not wasted in the Israeli economy and may even have had a higher rate of return than privately-financed R&D*"[109] (italics in original). The authors expressed confidence in the thrust of their main findings, namely that the mechanisms used in allocating Israeli government funds to support firm-based R&D, "seem to be doing their work properly in most cases, and that the more they manage to 'pick

107See, for example, Z. Griliches, "Productivity, R&D, and Basic Research at the Firm Level in the 1970's," *American Economic Review,* 76(1), 141–54, 1986; Z. Griliches and Frank Lichtenberg, "R&D and Productivity at the Industry Level: Is There Still a Relationship?" in Z. Griliches, ed., *R&D, Patents and Productivity* (Chicago: University of Chicago Press, 1984), pp 465–496; David Levy and Nestor Terleckyj, "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis," *The Bell Journal of Economics,* 14(2): 551–561, 1983.

108The Griliches et al., study indicated that it was not possible to obtain Israeli data that would have permitted assessment of whether or not government supported R&D in Israel generated spillovers. ("While the...aspect of ...externalities, may be the most important in evaluating the success of such support programs, our data will not permit us to pursue it," Griliches et al., *R&D Policy in Israel: Overview and Lessons for the ATP, Draft report, ATP,* 2000).

109Griliches et al., *R&D Policy in Israel: Overview and Lessons for the ATP, Draft report, ATP,* 2000, p. 48.

winners' the better." However, the authors explicitly noted that their estimates "should be treated cautiously;" the estimates of the coefficients for the grants variables are seen to be unduly high, pointing to potential problems in model specification, exclusion of relevant variables, or selection bias that originates in the way grant-receiving project or firms are chosen.

Other ATP-commissioned studies that bear on the topic of impacts of government sponsored R&D on firm productivity include work by Mariko Sakakibara, University of California-Los Angeles, and Lee Branstetter, Columbia Business School and the NBER. Their research found that participating in ATP consortia increased patenting in the funded areas above the level of patenting prior to the formation of the consortia. Another study that bears on firm productivity was carried out by Michael Darby and Lynne Zucker of UCLA and the NBER, and Andrew Wang, ATP economist. They point out that although there are arguments that government grants crowd out private R&D expenditures, they found evidence to the contrary for ATP. They concluded that ATP grants to private firms in fact increase the success of R&D in the recipient firms, noting that study results show these effects to be much more obvious for participant firms' total patenting than for the direct results of the funded research projects.

Diffusion of New Technology

Achieving ATP's ultimate goal of generating broadly based economic benefits requires technology diffusion. Models of technology diffusion abound.[110] As with other relationships on which a sizeable body of research exists, the applicability of off-the-shelf-models in designing an appropriate evaluation methodology becomes an early design question. For example, among the immediate questions to be answered: (1) Are the same variables used in other studies the most highly significant or explanatory variables affecting the adoption of ATP-sponsored technologies? (2) Do early commercial planning and collaborative relationships with the downstream firms and actors involved in commercializing the new technology affect rates and levels of diffusion?

[110]See, for example, M. Karshenas and P. Stoneman, "Technological Diffusion." In P. Stoneman, ed., *Handbook of the Economics of Innovation and Technological Change* (Oxford, UK: Blackwell, 1965), pp. 265–297.

ATP's Integrated Set of Strategies for Promoting Technology Diffusion

A NATO workshop designed to help policymakers in Central and Eastern European countries use technology transfer as a tool for transformation to a market economy provided ATP staff with an opportunity to review the program's approach to technology diffusion. The resulting paper identified a set of specific strategies intended by ATP to promote technology diffusion.[111] These strategies are summarized in Table 4–8.

The paper discussed ATP's attention to selecting projects with structures intended to foster commercialization and diffusion of new technology and illustrated seven organizational structures based on ATP projects.[112] The paper makes a logic-based argument that ATP projects have better diffusion prospects than they would in absence of the described set of integrated ATP strategies to promote diffusion, but does not prove it.

Analysis of Deployment Prospects for Selected ATP-Funded Technologies

In recognition of the complexity and difficulty of launching new technologies, and to further the early launch objective, ATP commissioned a team of researchers at ERIM, the University of Michigan's Transportation Research Institute, and the Michigan Manufacturing Technology Center's Performance Benchmarking Service to investigate the deployment prospects for a group of technologies funded under ATP's focused program in Motor Vehicle Manufacturing Technology.[113] The researchers looked at technologies with potential for adoption by small and medium-sized manufacturing enterprises. They selected for detailed analysis the following three ATP-funded technologies: (1) agile precision sheet-metal stamping, (2) machine tool process monitoring diagnostic system, and (3) motor vehicle rapid toolmaker. These were also chosen for their potential application outside

[111]See R. Ruegg, *Advanced Technology Program's Approach to Technology Diffusion,* 1999.

[112]Ibid., p. 15.

[113]Stanley M. Przybylinski, Sean McAlinden, and Dan Luria, *Temporary Organizations for Collaborative R&D: Analyzing Deployment Prospects,* Draft report, ATP, 2000.

Table 4–8. ATP Strategies Designed to Promote Technology Diffusion

- ✓ Select "enabling" technologies that are path breaking, multi-use, or infrastructural.
- ✓ Select projects with an organizational structure and set of participants that provide strong pathways to early applications.
- ✓ Select projects with up-front integrated research and business plans.
- ✓ Encourage companies to attract additional financial resources and collaborative relationships to strengthen pathways to technology deployment.
- ✓ Hold ATP-sponsored workshops to showcase funded technologies.
- ✓ Emphasize importance of technology diffusion during the project and in the post-project period.
- ✓ Focus on diffusion at the intra-firm, intra-team, intra-industry, and inter-industry levels.

Source: List of strategies summarized from Ruegg, "Assessment of the ATP," 1999, p. 19.

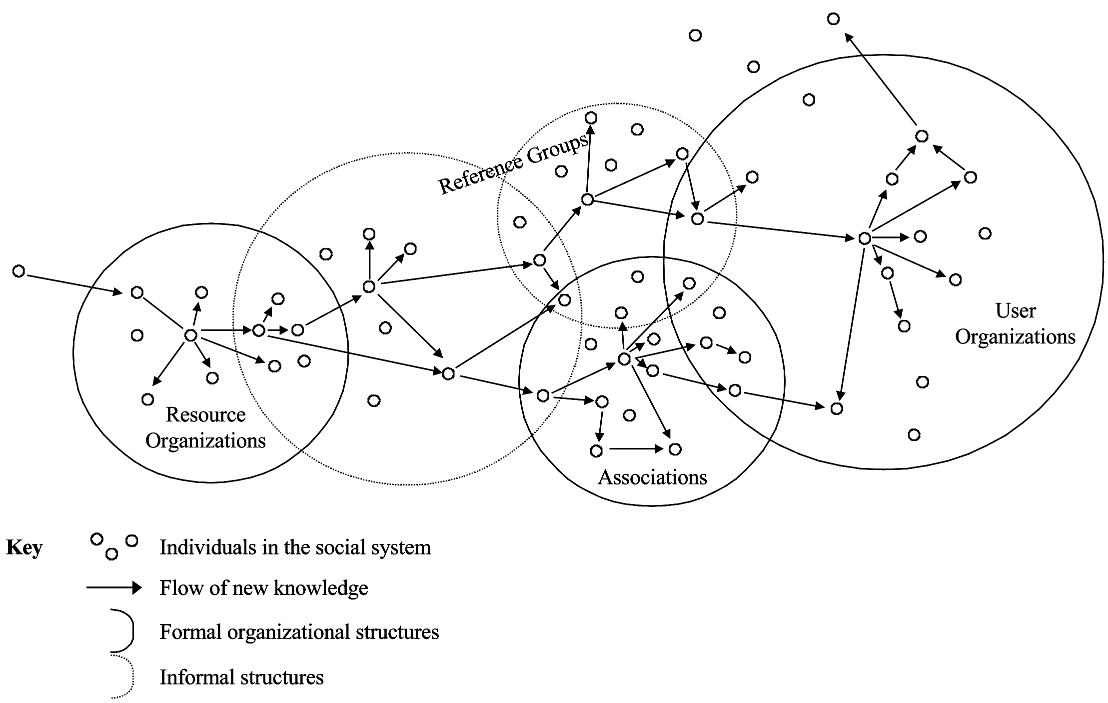
the automotive sector. The goal of the evaluation project was to identify ways to improve the prospects for broad deployment of ATP-funded technologies.

The researchers noted that all three of the ATP-funded projects used "traditional means" to encourage early use of the new technologies. They cited the presence of "lead users," beta testing at customer sites, informational meetings with leading companies, technical interchange meetings, promotion of the technologies at trade shows and technical meetings, technology transfer workshops, technology demonstrations, posting information at websites, poster sessions, and industry association activities. They cited sharp differences among the projects in their use of technical publications as a communications media, with the differences attributed to differing strategies to protect intellectual property. The researchers also noted the lack of available market research data at the time of the study relevant to the three case technologies.

The study report emphasized how important it is for the industry project team and the ATP project management staff to understand the innovation system within which the technology is to be deployed. A detailed knowledge of this system is necessary for gauging the commercialization prospects of technologies proposed in a given area. Figure 4–9 depicts conceptually an innovation system based on social interaction. Mapping social relationships in an innovation system can be useful in facilitating technology deployment and in assessing impacts.

An example of a barrier to deployment of new technologies is inherent in the authors' use of the term "competence-destroying innovations." Resistance to having one's competence destroyed by the appearance of a new technology

Figure 4–9. A Social Interaction View of Innovation



Source: Adopted by Przybylinski et al., *Temporary Organizations for Collaborative R&D: Analyzing Deployment Prospects,* 2000, from Havelock and Havelock.

can be expected, as can the need to develop new competencies in the adopting community. The authors suggested that studies to determine how a new technology may affect existing competencies, followed by remedial actions, such as awareness seminars, could improve the chances of successful deployment.

The authors identified another potential barrier to deployment in the requirement for "gating," or prerequisite, technologies that must be in place before the new technology can be adopted. As an example, they cited the need for sophisticated use of computer-aided design to be practiced in order for small- and medium-sized enterprises to benefit from one of the three new technologies. Concurrent engineering practice was another example of a gating technology identified by the study. Hence, identifying in advance any gating technologies and taking early action to enhance their use may help smooth the way for deployment of a new technology. The authors saw a potential role for NIST's Manufacturing Extension Partnership program to collaborate with ATP in this regard.

University-Industry Roles and Relationships

Since the early 1980s, a major thrust of federal and state government innovation policy has been to foster cooperation and collaborations between U.S. firms and universities. Several ATP studies have examined collaboration between firms and universities in projects funded by ATP.

ATP's authorizing language focused on the needs of U.S. firms and industries. Following this intent, ATP focused its early program design and selection criteria on variables and relationships deemed salient to industry, treating universities as supporting players to be involved in ATP projects as firms chose. But observing the behavior of firms that applied for ATP awards, it became apparent that collaborative relationships between the firms and universities were more important than suggested by the original program language. Over time it became evident from proposals submitted by firms to ATP that firms were choosing to include universities as R&D collaborators in major ways. But what is the role of universities in these projects, and how does their inclusion affect project outcomes? A dominant *a priori* answer is that companies turn to universities to help them plan and conduct very advanced research. Several evaluation studies have shed light on these questions, and offered a few surprises.

Bronwyn Hall, the University of California, Berkeley, Albert Link, University of North Carolina-Greensboro, and John Scott, Dartmouth College, used a sample survey of ATP projects to investigate university involvement and effects.[114] They concluded that projects with university involvement are more likely to be in areas of "new" science. They found—with the caveat that the sample was small—that projects with university involvement are likely to experience more difficulty and delay, but also are more likely not to be aborted prematurely. This finding seems consistent with the dominant paradigm that universities are helping companies take on difficult problems at the forefront of research and helping them ultimately succeed.

In a related study, Bruce Kogut and Michelle Gittelman, professors from the Wharton School and NYU's Stern School of Business, investigated public-private partnering among U.S. biotechnology firms. Their research also produced findings related to university involvement in ATP projects, that is, "firms with weak in-house research capabilities can strongly improve those capabilities through collaboration with university scientists."[115] They concluded that "...scientists who both publish and patent are critical channels through which scientific knowledge is applied to the innovations of the firm,"[116] and that partnering with university scientists improves a firm's ability to attract such research talent. Again, their findings support the dominant paradigm, broadening it to include the effects of university affiliation on the firm's ability to attract top researchers.

A somewhat different, challenging view of the relationship between universities and industry in ATP research projects emerges from a study done by Julia Liebeskind, University of Southern California's Marshall School of Business.[117] Pointing to what may be thought of as an inverted path of knowledge flow—not from university to industry, but from industry to university—the author states:

---

[114]Bronwyn H. Hall, Albert N. Link, and John T. Scott, *Universities as Research Partners,* NIST GCR 02–829 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

[115]Bruce Kogut and Michelle Gittelman, *Public-Private Partnering and Innovation Performance among US Biotechnology Firms,* Draft report, ATP, 2000.

[116]Ibid., p. 34.

[117]Julia Porter Liebeskind, *Study of the Management of Intellectual Property in ATP-Grantee Firms,* Draft report, ATP, 2000.

> More generally, the ATP may wish to pay more attention to the university-industry connection as one path for diffusion of technologies. It is apparent from these case studies that many scientists in firms believed that the science they were practicing was far ahead of university science. If so, collaborations between industry and universities of ATP-funded research could be one way in which industry advances could be fed back into education in the future.

Thus, the research sponsored by ATP of university-industry relationships extends the predominant paradigm to include more, and richer roles and effects than may have been apparent on the surface.

Summary of Research Informing Underlying Program Theory

This chapter has drawn models, concepts, and findings from 25 reports and papers that together have advanced understanding of ATP, conditioned expectations about the program's effects, and indicated ways to improve it. Implicit or explicit in this body of work are the major arguments used by economists to explain the rationale for ATP, including the view that enabling technologies tend to generate large spillovers; global economic competition is increasingly driven by technological advance; high-tech risks contribute to an R&D funding gap in the private sector; many advanced technological development projects require synergistic, multi-disciplinary, and multi-organizational collaborative efforts whose initiation may require an outside stimulus; and the nation's capacity for economic competitiveness and prosperity ultimately depends on the health of its innovative capacity which public-private partnerships can strengthen.

Because of the central role of the spillover concept in ATP's rationale, the program commissioned an early report on knowledge, market, and network spillovers—what they are, how they are generated, and how to increase them. Earlier studies showing that market spillovers tend to result from private firm innovation suggested both their potential importance and the fact that ATP would have to set a goal of generating higher-than-average spillovers to be successful as a public program.

To help explain the multi-dimensions of ATP to stakeholders, several models were developed. One model graphed ATP's impact as a trajectory in three dimensions of innovation space: knowledge creation, private firm benefits, and spillovers, explaining why ATP funding is not corporate welfare. Another model depicted ATP's impact occurring along two paths. A direct path, subject to greater influence by ATP, depicted accelerated technology development by U.S. firms. An indirect path of knowledge flows, the direction and timing of which is hard to predict, depicted ATP's main impact through supporting enabling technologies and encouraging the sharing of non-proprietary knowledge. Another important early step was to convert the concepts that emerged from modeling and hypotheses to measurable variables that could serve as program metrics and to develop an implementation strategy for data collection.

A study of factors associated with the success or failure of joint ventures represented an effort to better understand the connection between one of ATP's design features and related outcomes. Factors most important to success appear to include those that promote trust among project participants. The ATP's emphasis on collaboration is only one of a number of program features that could be subjected to such study. Thus, the study of program dynamics appears a relatively under-researched area within the broader effort to model the ATP's underlying theory and concepts.

Investigation of funding availability in the private sector for high-risk research and of private funding decisions in the face of risk provided evidence of a funding gap for high-risk research. Findings from two studies reinforce the view that there is a "Valley of Death" where insufficient funding for early stage, high-risk technologies exists despite large inflows of private venture funding. Further, findings support the view that this gap can be bridged at least in part by government without driving out private sector funding.

Study of private sector practices further suggests that the private sector has created no single, simple, or dominant "silver bullet" R&D project selection method that must be followed by a public sector program. Study findings point to multiple definitions of the "success" or "failure" of technical projects, of key differences between the private and public sectors in the appropriateness of using commercial viability as the only or primary measure of success for public sector technology development programs, and of the importance of spillovers as a major benefit of public-sector R&D programs.[118] Findings point to the interrelationship of technical and market risks, and to the relatively greater risks associated with market volatilities. Findings also suggest that linking R&D project selection to measures of market impact tends to increase the accuracy of forecasts about rates of return, hence, reducing market risk.

Studies of state technology programs have been useful in understanding the positioning of ATP relative to these other programs. Study findings suggest that ATP is complementary to, rather than competitive with state programs, and that innovating firms can and do benefit from both.

Studies of foreign counterpart programs have provided insights for ATP and have helped ATP meet its mandatory requirements to determine eligibility of foreign-owned firms for ATP participation. In addition, programs in Japan and Israel, with their longer histories and larger databases, have served as testing grounds for researchers developing ATP-commissioned assessment models. The results of these trial applications have also provided valuable insights relevant to ATP, such as evidence that the impact of a partnership program on firm productivity can be strongly positive and will likely be understated unless data are collected over an extended period.

Conceptual modeling of ATP's time horizon with delineation of types of outputs and outcomes expected to unfold over time has helped condition stakeholder expectations. Empirical studies of actual time horizons for different technologies have served as a reminder of the range of variation to be expected within the boundary of the general framework.

Analysis and testing of dominant paradigms, rather than their unchallenged acceptance, has led ATP to develop more appropriate models and concepts for the program. For example, several studies have challenged the dominant view that government funding lowers private firm productivity. Analysis of ATP's attention to project structure and program features, which may increase the propensity of projects for commercial development and technology diffusion, has also challenged the paradigm that a "one-size-fits-all" approach to estimating rates of technology commercialization and diffusion is appropriate. Studies of university roles and relationships with firms in innovation projects have both supported and challenged the dominant paradigm that knowledge generated by projects flows from universities to industry, with one study pointing to the importance of the reverse order of flow, from industry to universities.

This body of work represents an important investment by ATP because it lays important pieces of the analytical and conceptual foundation of good program management and good evaluation practice. As Spender has aptly noted: "Appropriate theory is badly needed if we are to make better sense of our experience of these programs." Clearly, the job of developing appropriate theory for partnership programs is not completed, but substantial progress has been made.

[118]Spender, "Publicly Supported Non-Defense R&D: The U.S.A.'s Advanced Technology Program," 1997, p. 51, referencing Adams, Stoffaes, and Graham.

CHAPTER 5

Survey Method

As discussed in Chapter 2, a survey, if carefully designed, collected, and administered, can reveal useful information about a program's development long before impacts can be discerned in other ways. A survey can provide information about the characteristics and activities of performers, early effects, and long-term expectations. This information can help program managers detect early accomplishments and early problem areas. It can also be of value in communicating with Congressional committees and other key stakeholders who want to know if a program is on track to achieve its defined goals.

This chapter describes how ATP's use of the survey method evolved, allowing evaluators to track the progress of ATP projects, to present aggregate statistics in meaningful ways, to gather data for case studies, and to shed light on questions of critical importance. The surveys described here range from simple to elaborate, from relatively inexpensive to costly, and from those performed by outside contractors to those performed in-house. They range from those that are relatively straightforward to analyze, to those that are intricate and complex and contain many levels of data. Further, the surveys presented here demonstrate the varied purposes served by this useful tool of analysis, and show how a program can build its expertise in the use of a method over time. Table 5–1 lists eight ATP-commissioned studies that have used survey as a method of research. The table indicates the main purposes of each survey, its approach, and any unique features.

*Table 5–1. Eight of Eleven Studies Using Survey Method Represented**

TITLE & DATE OF REPORT	DATE OF SURVEY	AUTHOR	PURPOSE	PROJECTS INCLUDED	FEATURES
Advanced Technology Program: An Assessment of Short-Term Impacts—First Competition Participants; 1993	1991	Solomon	To identify early indications of ATP effects	All projects funded in 1990	✓ Telephone interview ✓ Semi-structured interview guide ✓ Open-ended questions ✓ Included a brief customer satisfaction survey in unpublished memo ✓ Included estimates of proposal preparation costs ✓ Counterfactuals used to identify ATP effects
Survey of Advanced Technology Program; 1990–1992 Awardees: Company Opinion About the ATP and Its Early Effects; 1996	1993	Silber	To broaden scope to include early commercialization indicators and customer satisfaction feedback	All projects funded 1990–1992	✓ Telephone interview ✓ Questionnaire ✓ Closed-ended questions ✓ Individual responses not revealed to ATP ✓ Published customer satisfaction results ✓ Counterfactuals used to identify ATP effects
Development, Commercialization, and Diffusion of Enabling Technologies; 2000	1997	Powell and Lellock	To routinely track projects and participants from the outset through 6 years after project completion	All projects funded 1993–1997 (Note: all funded projects from 1993 forward are included in BRS)	✓ Electronically administered (first by diskette, now by Internet) and entered into the Business Reporting System (BRS) maintained by ATP staff ✓ Set of questionnaires targeting different project and post-project stages ✓ Counterfactuals used to identify ATP effects ✓ Conducted by ATP staff on an on-going basis
Small-Firm Experience in the Advanced Technology Program; 1998	1997	Powell	To compare progress of small firms with medium and large firms	All projects funded 1993–1996	✓ Data drawn from the BRS ✓ Focus on small firms ✓ Includes Z test statistics of significance

Table 5–1. (Cont'd)

TITLE & DATE OF REPORT	DATE OF SURVEY	AUTHOR	PURPOSE	PROJECTS INCLUDED	FEATURES
Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect; 2001	1999	Feldman and Kelley	To test hypotheses about ATP's impact on awardees vs. non-awardees and differences in their characteristics	All projects receiving awards in 1998 and half of non-winning proposed projects in 1998	✓ Telephone interview ✓ Selection of questions mailed in advance ✓ Included estimates of proposal preparation costs ✓ Regression models used to control for other explanatory factors ✓ Control group used to identify ATP effects
Advanced Technology Program; Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End; 1997	1996	Link	To collect data from participants of a joint venture for use in a detailed economic case study	Members of a single joint-venture project funded in 1990	✓ Survey data were used to support a case study ✓ Counterfactuals used to identify ATP effects
Universities as Research Partners; 2002	1998	Hall et al.	To collect data on university roles and effects in ATP projects	Sample of 54 projects funded between 1990 and 1997	✓ Telephone interview ✓ Interview guide ✓ Random stratified sampling process
Acceleration of Technology Development by the Advanced Technology Program; 1997	1996	Laidlaw	To assess how, why, and to what extent ATP affects cycle time for technology development and commercialization	28 projects funded in 1991	✓ Telephone interview ✓ Semi-structure interview guide ✓ Focus only on cycle time effects ✓ Counterfactuals used to identify ATP effects

*Note: Three additional studies by Powell, listed in Tables 3–2, 3–3, and 3–4, detailing development and use of the BRS survey are not separately listed here, as the material is covered adequately by the studies cited.

Gaining Early and Broad Perspective of a Program's Effects

At the earliest practicable time—as the program neared the end of its first year of operation in 1991—ATP commissioned a survey study of projects. The objective was to learn if the ATP awards were having identifiable effects and, if so, what they were. The impetus was two-fold: to aid internal program management and to answer stakeholder questions. Program administrators were eager for evidence that the new program was on track, and both supporters and detractors in the public policy community were looking for quick answers to their questions.

The ATP engaged Solomon Associates, a small consulting firm, to work with ATP staff in designing and carrying out this first survey.[119] In selecting the target population, the contractor and ATP staff concluded that the multi-year projects funded by ATP should be up and running a minimum of 6–12 months before being surveyed to allow sufficient time for short-run effects to manifest themselves. Thus, ATP decided to proceed with the survey at the end of its first year of first-round projects.

At the time of this first survey, the newly formed program was in an experimental stage. It had a small staff, an overall budget of approximately $10 million, and a budget for external evaluation studies of $25,000. In addition to the survey, during the first year of program operation, ATP used administrative funds to support development of a database of program applicants and awardees. This database helped ATP answer stakeholder questions about the characteristics of its projects: the number, size, and affiliation of applicants; number of single company projects and joint venture projects proposed and awarded; geographical extent of the program as indicated by the location of applicants and awardees; technologies proposed and funded; amounts of funding requested and offered in industry cost sharing; and other characteristics of applicants and awardees. The descriptive profiling of applicants and awardees, together with the descriptive survey statistics of awardees after their projects were underway, constituted ATP's initial evaluation effort.

[119] See Solomon Associates, *The Advanced Technology Program, An Assessment of Short-Term Impacts: First Competition Participants,* ATP, 1993.

Because only 11 projects were funded in the first year, it was an easy decision to include all of them in the survey—5 single company projects and 6 joint venture projects. Of the 35 organizations participating in the 11 projects, the survey was restricted to the 26 firms receiving ATP funding because, at that time, the program's focus centered on firms rather than universities and other organizations.[120] The sample included a range of firms in terms of the number of employees, sales volume, capitalization, and location.

Identification of a suitable respondent at each of the 26 companies in the survey was an iterative process involving ATP staff, the companies, and the contractor. Often the discussions led to the designation in smaller firms of the CEO as the respondent and the business contact or project's technical program manager as the respondent in larger firms. Early in ATP's evaluation program, then, the importance of correctly identifying the individuals to whom a survey is targeted was highlighted.

Because of the exploratory nature of this first survey, the survey designers decided to administer it by in-depth telephone interview, using an informal discussion style that followed a semi-structured interview guide and featured open-ended questions. The contractor, Samantha Solomon, conducted all of the interviews to preserve consistency and to provide the professional experience needed to pursue an open discussion that could accommodate unanticipated lines of inquiry while still covering the planned topics of the interview guide. While the topics covered by the interview guide were influenced by hypotheses about ATP's intended effects (see Chapters 3 and 4), the open-ended nature of the line of questioning allowed respondents to bring up other topics and effects freely and to dismiss topics they thought unimportant for them. The objective was to discover any effects that the project participants might have experienced from ATP participation. ATP asked the contractor to allow the respondents free rein in identifying and

[120] In the early years of the program, the focus was on capturing how ATP, which featured leadership of high-risk research by for-profit companies to develop broadly enabling new commercial technologies, differed from other government research funding programs that generally featured either university research of a more basic nature or development of technologies to serve a specific mission—primarily defense and energy. Since then, the role of universities, government laboratories, and other non-profit organizations in ATP-funded projects has emerged as substantial, and attention has been devoted to them in ATP's evaluation effort.

discussing effects, and to code the responses after the fact, rather than to use a pre-coded format.

After a brief discussion in which the interviewer indicated general familiarity with the project, respondents were asked if they had experienced any changes as a result of the project and, if so, to discuss the single most important effect from their standpoint. Many respondents mentioned effects anticipated by ATP, but they identified two additional effects. In fact, respondents often listed one of those unanticipated effects, a "halo effect," as the single most important effect of the award. The majority of the respondents—100% of the single company applicants—said receiving an ATP award bestowed a "halo" of enhanced credibility on the company (or words to that effect). This result heightened ATP staff's awareness of the prestige value of the award, apart from the funding itself. It also had implications for the method of announcing awards and other operational aspects of the program. The results of this open-ended line of questioning clearly demonstrated the advantage of taking an exploratory approach to the survey method in the early stages of a program's evaluation.

According to the contractor, respondents to the telephone survey tended to be emphatic in indicating when they thought a line of questioning was premature. They elaborated on areas of particular interest to them. Overall, they were described as willing and forthcoming in their discussions with the interviewer. There was 100% participation by the targeted respondents.[121]

---

[121]A question at the beginning of the survey was the willingness of companies to participate. ATP included in its cooperative agreements with the companies a provision that they would be expected to cooperate with ATP in evaluation studies. Factors favorable to their willing cooperation may have included the following: (1) The cooperative agreements had been negotiated in the previous year, and memory of the provisions may have been relatively fresh. (2) The agreement was for conditional cost sharing, and companies may have been more eager to please ATP than if the funding had been in the form of an outright grant. (3) Many of the companies were small, with the CEO as respondent, and the CEOs may have had the sense of a public duty to respond as well as a special enthusiasm for discussing their innovations. A major survey conducted in 2000 (see Maryann Feldman and Maryellen Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* NISTIR 6577 (Gaithersburg, MD: National Institute of Standards and Technology, 2001)) had a lower response rate among awardees, despite researcher efforts to increase it. The difference in response rates probably reflects in part the much larger sample size of the later survey (240 projects versus 11 projects), its greater use of closed-ended questions, and the fact that it was largely without the nurturing of one-on-one discussions of the researchers with the companies.

Table 5–2. Program Effects Treated in the First Survey of ATP Projects

- ✓ Research direction with, versus without, the ATP award
- ✓ Leveraging investment in a technology
- ✓ Reducing research costs (e.g., through collaborative activities)
- ✓ Attraction of additional funding
- ✓ Acceleration of technology development (i.e., time savings)
- ✓ Retention of existing research jobs or creation of new research jobs
- ✓ Engagement in collaboration and strategic alliances
- ✓ Change in competitive standing
- ✓ Plans eventually to commercialize the technology
- ✓ Change in technology infrastructure (e.g., linkages between or within sectors)
- ✓ Effect of applying to ATP on the company's strategic business planning
- ✓ Conversion by defense contractors to commercial production (respondents' topic choice)
- ✓ Impact of the ATP award on credibility of company and technology, i.e., "halo effect" (respondents' topic choice)

Source: Solomon Associates, *The Advanced Technology Program, An Assessment of Short-Term Impacts: First Competition Participants,* 1993.

The resulting interview data showed some of the anticipated effects to be strong factors, others weak, and some too early to tell. Table 5–2 lists effects of the program identified by this first survey. The last two effects listed were those raised by respondents but not anticipated by the researcher.

This first survey produced findings of considerable value to ATP managers. It showed that the projects were headed in the intended direction. It helped program evaluators and administrators better understand the types of impact the program was having and the relative timing of these effects. It identified some unexpected effects of a special nature, including the "halo effect." The first survey also indicated which data were relatively easy or difficult to obtain, and areas of inquiry to which the companies were particularly sensitive. The feedback was invaluable in structuring ATP's nascent evaluation program and, more specifically, in designing future surveys.

Extending and Deepening Survey Data on Program Effects

In 1993, three years after the program began, ATP initiated a much larger project survey that covered all 125 companies and consortia participating in the 60 projects funded from 1990 through 1992. The background obtained from the earlier survey, described in Chapter 5, offered insights in designing the larger survey.

Several options were considered in planning the second survey study. These options represented a tradeoff between survey continuity and adapting the survey to changing opportunities and issues. One option was to take a panel approach, whereby the original interview guide would have been used to re-interview the original group of respondents later in the project life cycles. This approach would have facilitated tracking emerging effects of the group of 26 companies in the original survey over the subsequent two years, but it would have been limited to this small, original group and the identical questions. Another option was to apply the original interview guide to a different group of respondents after one year of funding for comparability. This approach would have increased the size of the sample and allowed the comparison of progress for two different groups of funded companies at the same time in their funding histories. The results would have helped determine how representative were the results of the first survey, but it would not have allowed ATP to enlarge the scope of its inquiry.

Yet another option—the one taken—was to develop a new survey instrument and administer it to all projects that had received funding for at least six months. This approach had the advantages of allowing more extensive and in-depth coverage of a much larger sample. In addition to probing in greater depth each area of potential impact identified by the first survey, the second survey would explicitly ask about possible negative impacts. It would explore business goals, plans to commercialize new technologies, and progress towards commercialization. It would allow a comparison of progress over time, and would support analysis by size of company and by type of project (single company applicant versus joint venture). This latter survey approach was taken because the demand for quantitative information about the program's performance as a whole had intensified by late 1993, particularly in light of discussions about possible plans to increase its size substantially.[122] Furthermore, ATP was approaching the due date for a mandatory report to Congress on its achievements to date, and needed additional material for the report.[123]

The average length of the projects in the population to be surveyed was three years. A few of the first-funded projects had reached the end of ATP funding. Nearly half of the 60 projects surveyed had completed at least 50% of their research goals, while another 40% had completed 75% or more. Yet nearly all of the companies were still in the process of carrying out research to develop their technologies. Hence, the focus of the survey was still on early effects and not on ultimate, longer-term economic impacts. NIST statisticians were consulted on sampling strategy. Their advice to ATP was to survey 100% of the projects, and to include as many participating organizations as possible. This approach was recommended in order to allow the data to be analyzed in a variety of ways while maintaining sufficient responses for statistical significance.

ATP engaged an independent contractor to carry out the second survey. Again, it was decided that the survey would be conducted by telephone interview with a single, qualified analyst, Bohne Silber, conducting all of the interviews.[124] This second survey used a detailed questionnaire, consisting mainly of closed-ended questions in contrast to the emphasis on open-ended questions in the first survey. The contractor worked closely with ATP staff to obtain background on the program and to develop the questionnaire, which was pre-tested and revised several times before it became final. Two versions of it were created to decrease the time burden: a "long form" to be administered to all single company applicants and to joint venture participants who indicated progress in commercializing results from their ATP projects, and a "short form," without the questions on

---

122The Clinton Administration released a plan in 1993, titled "A Vision of Change for America," to make ATP the flagship of an economic program that emphasized economic prosperity driven by technological advance.

123Advanced Technology Program, *Report to Congress: The Advanced Technology Program: A Progress Report on the Impacts of an Industry-Government Technology Partnership,* NIST–ATP–96–2 (Gaithersburg, MD: National Institute of Standards and Technology, 1996), drew heavily on survey results as well as the results of case studies and site visits.

124See Silber & Associates, *Survey of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects* (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

commercialization and business, to be administered to joint venture participants who indicated no current involvement in commercialization efforts. Wherever possible, conditional questions were used that would screen out a number of subsequent questions and branch to another part of the questionnaire. For example, if the interviewer received a negative response to the question "Have you engaged in collaborative relationships?" then none of the subsequent questions on collaboration would be asked. The questionnaire in its long form contained 134 questions and took about 90 minutes to administer if all the questions were applicable. The short form took 70–75 minutes if all the questions were applicable. In most cases not all the questions were applicable.

Respondent were informed in advance that their responses were confidential and would not be revealed to ATP staff. The purpose was to encourage the company representatives, most of whose companies were still receiving funding from ATP, to be candid in their responses. A disadvantage of this approach was that ATP did not receive the data files, and had to go back to the contractor for subsequent analysis of the data.

The survey collected background information on each organization and project. It asked if any positive or negative effects on the environment, health, or safety were expected, since the detailed questions focused on direct economic effects.[125] It asked the respondent to classify the long-run expected technical outcome of the project in terms of a new or improved product, service, or process. It also asked the respondent to classify the level of progress toward accomplishing their R&D plan. Because assessment of projects' technical achievements was otherwise disaggregated in ATP and held in the files of individual ATP technical program managers, survey statistics provided the only consolidated measure of technical progress for most of the program's first decade.[126]

[125]ATP defined its mission in terms of delivering broadly based net economic benefits, taking into account any related environmental, health, and safety effects, positive or negative. For example, a project that developed process technology with reduced toxicity to a large population of workers was considered to have broad-based economic benefits. In short, it sought to take into account to the extent possible all effects of ATP affecting the economy and quality of life for U.S. citizens.

[126]The economic evaluation surveys did not attempt to measure in detail the achievement of technical milestones; this duty was assigned to ATP's technical program managers who managed the process in a distributed way. Toward the end of the program's first decade, a database to track technical milestones of the portfolio of projects was introduced in ATP as an additional management tool.

The survey focused, in part, on the respondent's plans to commercialize their developing technology. The inquiry attempted to identify any emergent commercial applications of the technology that were not in the original proposal. New applications are significant because it indicates that a funded technology is enabling a variety of commercial activities. The inquiry also probed the companies' progress in bringing their technology to market in a specific application. To illustrate the level of detail, Table 5–3 gives an example of a series of commercialization questions taken from the Silber survey questionnaire. As would be expected, companies farther along in their research projects were more likely to exhibit commercial activity.

Another focus was on capturing information that would suggest the generation of knowledge spillover benefits. Table 5–4 illustrates several questions relating to that topic.

Collaborative relationships were another featured topic on the questionnaire. The intention was to discover the extent and purpose of collaboration, the role played by ATP, how well the collaborative relationships were working, and who was collaborating with whom. Table 5–5 gives examples of questions related to collaboration.

In addition to the topics of Tables 5–3 to 5–5, the survey covered employment effects, competitive standing, attraction of additional funding, and leveraging of research funds. This survey remained a primary source of performance data for ATP for two years. The survey questionnaire, which is available to the public, also provided the basis for developing ATP's next major survey tool.

Establishing Routine Project Reporting by Electronic Survey

By the mid-1990s, ATP decided to survey all organizations participating in its funded projects on a regular basis. It decided to replace the occasional telephone survey administered by an outside contractor with an electronic survey administered by ATP staff. ATP staff further refined and substantially extended the previously used questionnaire to better track the progress of individual projects towards delivering economic benefits, and to collect data for reporting under the Government Performance and Results Act of 1993 (GPRA).

Table 5–3. Illustrative Survey Questions on Commercial Progress

QUESTION NUMBER	QUESTION	No	Yes	Not sure	Not applicable
41	To date, has your company taken any steps toward marketing the products, processes or services that you ultimately expect from the ATP-funded projects?				
42	Have you held negotiations with potential alliance partners?				
43	Have you held licensing negotiations?				
44	Have you completed product or process definition?				
45	Have you completed concept testing with customers?				
46	Have you completed product or process development?				
47	Have you developed a lab prototype?				
48	Have you developed a production prototype?				
49	Have you set up a pilot production or commercial demo?				
50	Have you determined production rates?				
51	Have you conducted a sales and revenue forecast?				
52	Have you conducted other market analyses?				

Source: Silber & Associates, *Survey of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects, 1996, Survey Questionnaire,* Appendix A.

Table 5–4. Illustrative Survey Questions Relating to Knowledge Spillovers

QUESTION: Do you disseminate or plan to disseminate non-proprietary information—again, we're speaking about your work that's not confidential—about the ATP-funded technology through any of the following:

QUESTION NUMBER	QUESTION	No	Yes	Not sure	Not applicable
98	✓ with companies, for joint R&D				
99	✓ with companies who are suppliers				
100	✓ with companies, for production purposes				
101	✓ with companies, for customer access				
102	✓ with state government				
103	✓ with federal government, as a partner in R&D (not ATP)				
104	✓ with federal government, as a source of technology for further development				
105	✓ with federal government, as a partner for other purposes (specify: ________________)				
106	✓ with university, as a partner in R&D				
107	✓ with university, as a source of technology for further development				
108	✓ with another entity as a partner in R&D (specify: ________________)				
109	✓ with another entity as a source of technology for further development (specify: ________________)				

Source: Silber & Associates, *Survey of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects,* 1996, Survey Questionnaire, Appendix A.

Table 5–5. Illustrative Survey Questions about Collaborative Partners

QUESTION: For each of the following types of collaborative relationships you have had, tell me how well overall the collaboration is working:

QUESTION NUMBER	QUESTION	No	Yes	Not sure	Not applicable
98	✓ with companies, for joint R&D				
99	✓ with companies who are suppliers				
100	✓ with companies, for production purposes				
101	✓ with companies, for customer access				
102	✓ with state government				
103	✓ with federal government, as a partner in R&D (not ATP)				
104	✓ with federal government, as a source of technology for further development				
105	✓ with federal government, as a partner for other purposes (specify: ___________)				
106	✓ with university, as a partner in R&D				
107	✓ with university, as a source of technology for further development				
108	✓ with another entity as a partner in R&D (specify: ___________)				
109	✓ with another entity as a source of technology for further development (specify: ___________)				

Source: Silber & Associates, *Survey of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects,* 1996, Survey Questionnaire, Appendix A.

Several advantages were seen to having ATP administer and manage these next surveys of project participants. ATP staff is under strong legal requirements to protect the proprietary and confidential information of applicants and award recipients and to abide by nondisclosure rules. The companies are accustomed to interacting with ATP staff, and would require less administrative time than is needed of ATP staff to help coordinate interactions between the contractor and the companies. Most important, maintaining internal control of the survey would make it easier for ATP to construct an integrated set of databases supporting the comprehensive statistical analyses of all participants in all projects—an important tool of project and program management. Internal control over project data would give ATP more flexibility in generating a variety of analytical reports on a fast turnaround basis to respond to specific stakeholders' requests.

The ATP-administered, electronic survey of project participants is known as the "Business Reporting System" (BRS).[127] It covers all projects from 1993 forward, and pushed beyond the Silber survey in gathering data on technical and economic progress. Its coverage extends not only to the lead companies, but also to other joint venture participants, universities, and not-for-profit organizations. Until recently, the BRS was administered using customized diskettes mailed from ATP to the respondents, completed by them, and returned to ATP for downloading into the BRS database. As its first decade ended, the BRS was largely converted to a web-based system.

To help ATP establish a baseline, project participants are required to report at the outset of their project their planned application areas for the technology and their strategies for commercialization. At the end of each year, participants report on progress toward implementing their commercialization strategies, short-term economic impacts of their projects, and any changes in plans. At the conclusion of their projects, they report on their overall accomplishments. During the post-project period, they report three additional times—every other year over six years, according to the "Terms and Conditions" of their cooperative agreement. Extending the survey six years beyond project end is ambitious because the difficulty in tracking project effects tends to increase over time. Difficulties may stem from personnel changes within the firm, dimming memories about the ATP-funded part of the effort, transfer of developing technology to other parts of a company or to collaborators who may not know or care about the ATP-source of research funding, other sources of funding becoming predominant, mergers and acquisitions, and a blending of the ATP-supported technology with other technologies that blurs its ATP origins.

[127]Multiple reports based on BRS data have been published by Jeanne W. Powell, project manager for development of the BRS, and various coauthors. The BRS was first described by Powell in "The ATP's Business Reporting System: A Tool for Economic Evaluation," paper presented at the Conference on Comparative Analysis of Enterprise Data in Helsinki, Finland, 1996.

Table 5–6. Components of ATP's Business Reporting System

TYPE OF REPORT	NUMBER OF REPORTS OF EACH TYPE
Baseline report	1 for all projects
Anniversary reports	1–2 for single company projects; 1–4 for joint venture projects
Close-out report	1 for all projects
Post-project reports (every other year for 6 years)	3 for all projects

Source: Powell, "The ATP's Business Reporting System: A Tool for Economic Evaluation," 1996.

Over time, the emphasis in the BRS reports shifts increasingly from early indicators of progress to economic impacts. Table 5–6 summarizes the several parts of the BRS.

The resulting database is a unique management, policy, and evaluation research tool. It captures the linkage of technologies under development to applications in numerous industry sectors. It allows ATP to see major tendencies and emerging trends across its portfolio of projects. The data can support varied analyses by industry sector, technology area, geographical location, funding year, collaborative relationships, type of ATP competition, organizational size and type, and other characteristics.

Since the beginning of the program, for example, small business advocates have worried that small companies might not fare well in the program relative to larger companies. BRS data allows evaluators to compare small firms with larger firms with respect to their participation, strategies, and commercial progress.[128] Table 5–7

[128]See Jeanne W. Powell, *Business Planning and Progress of Small Firms Engaged in Technology Development through the Advanced Technology Program,* NISTIR 6375 (Gaithersburg, MD: National Institute of Standards and Technology, 1999).

Table 5–7. Examples of Variables for Comparing Small and Larger Firms Using BRS Data

VARIABLE	Small firms	Larger firms	Z-test statistic
Effects of ATP funding on			
✓ R&D scope			
✓ Willingness to take on technical challenges			
✓ Willingness to take on long-term research			
✓ Position in R&D cycle			
✓ Change in industry investment			
Credibility			
✓ With investors			
✓ With customers			
✓ With suppliers			
✓ With management			
Progress toward commercialization			
✓ Production prototype			
✓ Set up pilot production			
✓ Began production			
✓ Adopted process improvement			
✓ Earned product revenues			

Source: Powell, "*Business Planning and Progress of Small Firms Engaged in Technology Development Through the Advanced Technology Program*," 1999.

lists some of the dimensions on which Powell has compared small and large firms. She computed Z-test statistics to determine the level of significance of the statistical difference in the two groups. Findings, discussed in Chapter 9, suggest that small companies are thriving in the program.

Because of the confidential and proprietary nature of much of these data, ATP publishes results in aggregate form only.

Soliciting Feedback by Survey on Customer Satisfaction and Marketing Issues

In addition to providing statistics that describe program effects, surveys can be used to assess customer satisfaction and to address marketing issues. Applied to a public program such as ATP, customer satisfaction means determining how well the relationship is working between the program and the organizations with which it directly interfaces in carrying out its mission. In ATP's case, the organizations it funds may be thought of as counterparts to a business firm's customers. The use of the term "customer satisfaction" in this context does not imply that the funded businesses are ATP's ultimate customer. As a public program, U.S. citizens are ATP's ultimate customers. But as a counterpart to business use, the funded organizations are those with whom ATP deals directly, and the success of those interactions affects the success of the program. In the case of a public program, which by definition is operating outside private markets, "marketing issues" refers to questions about how the services offered by the program become known by, and are perceived by, the public.

Soliciting early feedback from customers is particularly important when a new endeavor creates many new sets of relationships. It is preferable to find out as soon as possible how well the relationships are working, rather than simply to assume they are working well. But even though program administrators want to know how they are doing in these new relationships, they are not immune from disliking criticism and being defensive in the face of it. For this reason a third-party assessment, with full confidentiality to respondents, is essential.

ATP's published customer satisfaction survey met these tests. It was conducted as part of the second contractor survey, and the results included as part of the larger report.[129] Questions were asked about the resources and personnel of NIST technical support, the ATP professional staff, and all aspects of the program over which ATP has control, including the solicitation of proposals, review and evaluation of proposals, selection of award recipients, and project monitoring.

[129]See Section 4, "Satisfaction with NIST and ATP," in Silber & Associates, *Survey of Advanced Technology Program, 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects,* 1996.

Respondents were also encouraged to give specific comments regarding their views about working with ATP.[130]

A marketing issue was also addressed by this survey. Respondents were asked how they learned about ATP. The objective was to find out which outreach efforts were most effective. Several other marketing issues have been addressed by other surveys.

After its first competition, ATP received complaints from several companies that the cost of writing a winning proposal was too high. In its first survey ATP included a question about cost of proposal preparation in order to examine this complaint.[131] Survey findings indicated that winning proposals ranged in preparation costs from a low of several thousand dollars to a high of several hundred thousand dollars. The fact that proposals with low preparation costs were able to win awards supported ATP's contention that proposal content—not preparation cost—mattered most. At the same time, the perception of prospective applicants about preparation costs is likely an important factor in shaping their decisions on whether or not to submit proposals.

The question of proposal cost was re-surveyed nearly 10 years later by Feldman and Kelley,[132] with much the same result: Reported preparation costs were extremely variable across winning proposals, ranging again from several thousand dollars to several hundred thousand dollars.[133]

The survey by Feldman and Kelley addressed two other issues important from a program marketing perspective: (1) Do the applicants, regardless of the outcome, consider the ATP review and selection process fair; and (2) do they plan on

130Care was taken to distinguish in the survey between those matters over which ATP has control and can change, and those outside its control, such as legal requirements for government audits and limits on the time allowed for a project to be carried out.

131The survey conducted by Solomon Associates (published in 1993) included a few customer satisfaction and marketing questions that were delivered to ATP informally in a memo and not included in the published report on impact assessment.

132See Feldman and Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* 2001, p. 23.

133There were no data available on decisions of prospective applicants not to submit because of perceptions about the level of preparation costs needed to win an award, or on how proposal quality is affected by costs.

applying to ATP again in the future.[134] The majority, whether they received an award or not, viewed the process as fair, and the majority planned on applying to the program again.

Using Survey for Case Study and to Address Research Questions

The previous examples of the survey method focused on providing aggregate descriptive statistics for a program overall. But the survey method can also be used to collect data for an individual project case or to investigate particular research questions. This section illustrates the varied use of the survey method in evaluation research, using examples from ATP.

Surveying Joint Venture Members to Compile Case Study Data

The survey method can be used to gather data in support of other studies. In fact, in the first case study of an ATP joint venture project, Professor Albert Link of the University of North Carolina-Greensboro used a survey to collect economic data from participants.[135] The survey targeted participants in the Printed Wiring Board (PWB) research joint venture, a five-year effort aimed at a turnaround in an industry sector in sharp decline. To establish a lower bound estimate of the economic value achieved by the joint venture,[136] the survey examined a subset of project tasks that participants said they would have started even in the absence of ATP support thereby introducing a counterfactual element. All members of the joint venture completed the survey for each of five major research groups.

134Feldman and Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* 2001, pp. 34–35. The main purpose of the survey was not to gather marketing data. Rather, data of relevance to program marketing were compiled in conjunction with testing the proposition that an ATP award certifies quality, resulting in a reputational or halo effect.

135See A. N. Link, *Advanced Technology Program; Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End,* NIST GCR 97–722 (Gaithersburg, MD: National Institute of Standards and Technology, 1997).

136No attempt was made to estimate the aggregate value of impacts from adoption of the new technology because the project was only just concluding and the technology just beginning to be adopted. However, early adopters provided anecdotal evidence of benefit that is included in the case study report.

Table 5–8. Competitive Position of Member Companies in the World PWB Market

As a result of my company's involvement in the PWB program, my company's share of each of the following segments of the PWB market has (choose one for each applicable market segment): increased; stayed the same; decreased; no opinion.

MARKET SEGMENT	My Company's Market Share Has...
Automotive	
Communications	
Consumer electronics	
Computer and business equipment	
Government and military	
Industrial electronics	
Instrumentation	

Source: Link, *Advanced Technology Program; Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End,* 1997, p. 43.

The survey had three parts. In the first part of the survey, the counterfactual part, Link asked joint venture members to quantify, by project task, a number of related metrics comparing the actual project technological state to a hypothesized technological state that would have existed at the same time in the absence of ATP's financial support of the joint venture. From the results, he identified cost and time savings based on those research tasks the members thought they would eventually have done without ATP, and he separated out the tasks they otherwise would not have done at all.

In the second part of the survey, Link collected technology diffusion information: number of papers presented; number of conferences attended in which joint venture members talked about the project's activities; and percentage of PWB supplier industry with which members interfaced in conjunction with the project.

In the third part of the survey, Link collected information about changes in international competitiveness that members believed were linked to the PWB joint venture. He looked at changes in the companies' share of each market segment due to their participation in the project, and changes in the United States PWB industry's share in world markets due to accomplishments of the PWB joint venture as a whole. Survey questions regarding the competitive position of member companies are shown in Table 5–8.

Using Survey to Explore Research Questions

The survey method may be applied to individual research questions. For ATP, a question of central importance is what difference ATP makes for the projects it funds. Or, expressed counterfactually, what would have happened had there been no ATP. These questions are fundamental to both the politics and economics of the program.

As indicated previously, establishing the fact that the larger portfolio of ATP-funded projects has had a substantial positive impact is a necessary but insufficient argument for the program's existence. Both economists and politicians want to know how much of the impact is attributable to ATP. Multiple evaluation methods have been used to answer this question, and prominent among them was the survey method. An account of how the survey method has been used to tackle this difficult question is instructive to the field of program evaluation.[137] It is a story that demonstrates increasing sophistication in both the questions asked and the efforts to answer them.

Early Surveys Address Counterfactual Question

In accordance with good evaluation practice, both of the early contractor surveys of ATP project participants attempted to isolate the effects attributable to ATP. The first survey[138] simply asked participants "with what likelihood would your organization have pursued the development of your technology, without the ATP award." If the response indicated they likely would have pursued the technology development, a follow-on question was asked: "Without the ATP award, would you have pursued it at about the same level of effort, with the same ultimate

---

137Other methods of evaluation also investigated the "with and without ATP" question. These efforts are treated in other chapters in Part II.

138Solomon Associates, *The Advanced Technology Program, An Assessment of Short-Term Impacts: First Competition Participants,* 1993, p. 13.

goal?" Almost all the program participants responded either that they would not have pursued their technology development projects at all without ATP or not with the same level of effort and not with the same goal. Anecdotal information was solicited of respondents about how the projects would have differed without ATP. This finding conforms to ATP's expectations since ATP's selection process was geared not to fund projects that were expected to proceed in the same way without ATP funding.[139]

The second survey[140] probed deeper to determine the effects attributable to ATP. Table 5–9 lists some of the companies, including their number sequence in the survey as reference. A combination of open-ended and closed-ended questions was used, and similar questions were approached in several different ways.

Results from both of these earlier surveys supported the conclusion that ATP made an important difference in the timing, resources, and level of risk exposure of participating companies. The effects of ATP as indicated by the responses to these counterfactual questions appeared totally consistent with its mission. But opponents continued to charge that the effects would have happened anyway. To better respond to stakeholders, particularly skeptics, ATP's evaluation efforts continued to pursue the counterfactual question with more diligence.

BRS Survey Regularly Probes Counterfactual Question

When ATP implemented the BRS electronic survey system in 1993, the question of ATP's impact—apart from the impact of the projects themselves—was high on the list of evaluation study topics. The BRS survey adopted many of the questions in the Silber survey and added more on timing, resource commitment, and risk acceptance. Indeed, counterfactual elements were incorporated throughout the BRS survey. The objective was to test in multiple ways whether ATP funds were leveraging private investment dollars, or substituting for them; whether ATP was

139From the outset of the program, applicants were asked to explain how their work would be different with and without ATP funding. Later, this requirement was supplemented with a provision in the application kit that required applicants to document their specific search for funding prior to applying to ATP and the reasons they were turned down.

140Silber & Associates, Survey *of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects,* 1996.

Table 5–9. Survey Questions Probing the Counterfactual: With and Without ATP

QUESTION NUMBER	QUESTION
63	How, if at all, has the award changed things for your company? What has the award meant?
64	With respect to your company's ability to afford and engage in high-risk research, would you say the award has benefited you to a ❑ great extent, ❑ moderate extent, ❑ small extent, or ❑ not at all, not sure. Describe how/why: _________________ ____
65	Has the amount of R&D money invested by your company in this project changed as a result of the ATP award, or would it have been the same without the ATP award? ❑ would not have pursued without the award, ❑ increased, ❑ decreased, ❑ stayed the same, ❑ not sure.
66	If increased or decreased (ref. # 65), by about how much, in estimated dollars? $__________?
67	Without the ATP award, how likely would your organization have been to pursue the development of this technology? Would you say: ❑ extremely likely, ❑ fairly likely, ❑ not too likely, ❑ not at all, or ❑ not sure? Describe how/why: _______ ____
68	Without the ATP award, would your organization have pursued development of the ATP-funded technology at about the same level of effort, with the same ultimate goal, or would the level of effort and goal have been different? ❑ same effort and goal, ❑ different effort and goal, ❑ not sure, ❑ would not have pursued without the award.
69	What difference did the ATP award make? What did you do that you wouldn't have done anyway?
70	In terms of the technology being funded through the ATP award, where in the R&D cycle would your company probably be without the ATP award? Would you say that you're ahead of where you would have been, at about the same place, or behind? ❑ ahead, ❑ same place, ❑ behind, ❑ not sure, ❑ would not have developed technology without ATP award.
71	If ahead (ref. #70), how much ahead of schedule?

Table 5–9. (Cont'd)

72	To what extent, if any at all, will you be able to make a better product, in terms of quality and performance, because of the ATP award? Would you say to a ❑ great extent, ❑ moderate extent, ❑ small extent, ❑ not at all, ❑ not sure, ❑ would not have developed technology without ATP? Describe how/why and the financial impact: ____
73	What about process improvement? To what extent, if any at all, has your company adopted process improvements as a result of the ATP-funded project? To a ❑ great extent, ❑ moderate extent, ❑ small extent, ❑ not at all, ❑ not sure, ❑ would not have developed technology without ATP.

Source: Silber & Associates, *Survey of Advanced Technology Program 1990–1992 Awardees: Company Opinion About the ATP and its Early Effects,* 1996, Survey Questionnaire, Appendix A.

encouraging companies to take on more technically challenging projects than they otherwise would; and whether it was accelerating technology development. The results of the on-going BRS survey substantiated and extended results of the earlier surveys. It provided evidence that ATP accelerated the participants' technology development, enabled them to take on high-risk R&D, and stimulated them to spend more of their own funds on R&D than they would otherwise have invested.

Still, opponents of the program continued to assert that ATP simply substituted public dollars for private R&D dollars and did not cause the effects found by the evaluation studies. This view held strong and steady in some quarters despite a 1996 survey by the General Accounting Office (GAO) of "near winners,"[141] that found about half discontinued their projects altogether when they failed to win an ATP award, while nearly all that continued did so at a reduced level of activity. This finding was consistent with the finding of the earlier surveys that ATP was

[141]The "near winners" group was not necessarily a sound control group because GAO did not adjust for the reason the sample projects were not selected as winners. For example, ATP may have discovered evidence during oral reviews of the semi-finalist projects that the projects would likely go forward without ATP funding.

either enabling projects to start that otherwise would not have started, or accelerating or expanding the scale or scope of those that would have started—effects totally in keeping with its legislated mission. Feldman and Kelley confirmed the findings in a later survey.[142]

Focused Surveys Seek Details on ATP's Effect

In 1996, a study was launched which used the survey method to explore the details of how and why ATP might accelerate technology development and commercialization, what this might be worth to companies, and whether there were effects on timing that extended beyond the ATP project. The survey, carried out as a doctoral dissertation,[143] used structured telephone interview of company participants in 28 projects funded by ATP in 1991. All of the questions centered on the companies' applied research and technology development cycle time. The purpose was to see if more light could be shed on ATP's purported effect on technology development time.

The survey found that reducing applied research cycle time was important to the participating companies. It found that they gave concrete reasons for the importance of reducing research time, that the median time savings from ATP participation was put at 50% or three years, and that savings in research time for most of the companies translated into faster time to market. Most of the respondents were able to give either a quantitative or qualitative ballpark estimate of the value of acceleration, with a median value in the millions of dollars for every year saved. The responses were compatible with ATP having a leveraging rather than a substitutive effect. Respondents listed five major ways participating in the program helped them reduce cycle time, one of which was ATP funding. They explained how some of these effects carried over to benefit other non-ATP technology development projects. The findings confirmed and extended previous survey findings

142See Feldman and Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* 2001.

143Frances Laidlaw prepared the dissertation in partial fulfillment of a doctoral degree at George Washington University. Laidlaw also published a condensed version of her research as a NIST publication, where she served in a part-time capacity as an Industry Consultant to ATP. See Frances Jean Laidlaw, *Acceleration of Technology Development by the Advanced Technology Program: The Experience of 28 Projects Funded in 1991,* NISTIR 6047 (Gaithersburg, MD: National Institute of Standards and Technology, 1997).

and provided further evidence that ATP was making a difference. However, these findings remained insufficient proof for some.

A later survey focused on universities as research partners in ATP projects.[144] The study used a random stratified sampling process to identify 54 companies for the survey. Category-specific survey instruments were faxed to each respondent, with multiple follow-ups by telephone to increase the response rate. The sample included joint ventures and single applicants, each with and without university involvement.

Recent Surveys Use Randomly Drawn Control Groups to Strengthen Tests of ATP's Effect

The Feldman and Kelley survey of large random samples of winners and non-winners from ATP's 1998 competition,[145] discussed earlier in the chapter, also investigated the question, "Does ATP funding make any difference?"[146] Rather than ask winners what they would have done without the ATP award, this survey asked a randomly selected control group of non-winners one year after proposing to ATP if they had proceeded with their proposed projects, and if they had, how the scale of work compared with what had been proposed to ATP. The sample groups included 119 award winners and 122 non-winners. The investigators used independent sources to verify survey responses concerning employment, financing, and the founding date of the company, and matched survey records with data from the proposals and the firm's prior history of applications and awards. The survey found that most non-winners did not proceed with their R&D plans and that most of those who proceeded pursued the project at a smaller scale than what they had proposed to ATP. In addition, the survey found differences in the behavior of winners and non-winners in terms of their propensity to share knowledge, and in their ability to raise funding from other sources. It confirmed the existence of, and

---

144Hall et al., *Universities as Research Partners,* 2002.

145The 1998 group of applicants was chosen for survey in order to effectively time the administering of the questions; that is, soon enough that applicants would not have forgotten and delayed enough to find out what they subsequently did.

146Feldman and Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* 2001.

provided a measure of, the "halo effect" identified by participants 10 years earlier in ATP's first survey as one of the most important effects of ATP.

ATP's most recent survey, under development at the time of this study, takes the investigation of differences in winners and non-winners yet a step further.[147] It is to focus on the 2000 competition, and capture what is different between ATP projects and other R&D projects in the company. Like the previous survey, it also seeks to capture differences between winners and non-winners in R&D project characteristics, R&D financing, and ATP's role. By sampling the level and sources of funding support for the proposed technology before and after submittal of the ATP proposal, and researching how winning and non-winning projects differ from other R&D projects in the proposing companies, this new survey is expected to take another major step toward defining ATP's effect.

Summary of ATP's Use of the Survey Method

From the program's beginning, the survey method has played a vital role in ATP's evaluation activities, helping to define the program's impact and value. Surveys have been used to describe features of the entire portfolio of projects, to analyze the progress and effects of funded projects, and to identify the effects of ATP. The survey method has been used as an adjunct to other methods to compile needed data. It has served as a tool to gather feedback from ATP's clients, and thereby shaped the marketing and operation of the program. It has been used in increasingly sophisticated ways to expand knowledge about the program and its effects, and to investigate key questions of interest to the evaluation and policy communities.

The examples presented in this chapter have illustrated many characteristics of sound survey practice. To mention only a few, the development of the surveys has given considerable attention to the formulation of questions, the sample populations surveyed, the method of administering the survey, the administrator

[147] At the time of this report, plans were in place for the survey questionnaire to be administered by Westat, an independent research firm. The planned survey, "Survey of ATP Applicants, Year 2000," received OMB approval to proceed. Andrew Wang, staff economist at ATP, is project manager for the study.

of the survey, and the presentation and interpretation of results to diverse audiences. Attention has been paid to identifying appropriate individual respondents within organizations, and to the timing and sensitivity of the questions asked. Anonymity has been provided when needed to encourage greater candor. The data have been protected and used in ways that do not compromise confidentiality of participant information. Key issues have been pursued in increasingly sophisticated ways, refining and extending previous approaches and results. Important issues have been pursued in different ways, at different times, and by different surveys to confirm and extend the knowledge base. The use of a feedback loop has ensured that future surveys have built on what has been learned from previous ones, resulting in a growing expertise within the organization on the use of the survey method in support of evaluation.

The continuing evolution of ATP's survey development illustrates how a program can broaden and deepen its use of an evaluation method over time, building on previous work as it adapts to changing issues, challenges, and emerging opportunities. The breadth of ATP's experience suggests the survey method is a tool that has a place in every evaluation program.

CHAPTER 6

Case Study Method

ATP has used case studies for multiple purposes throughout its first decade. Case studies have helped make the technical and economic aspects of its complex technology projects more accessible to non-scientists. Case studies have helped explore the genesis of projects and programs, and tell the stories of the people and organizations behind the projects. Case studies have helped answer why and how questions, explain roles and goals, investigate project dynamics, track progress, identify market applications, measure outcomes, and—performed in multiples—estimate portfolio performance.

All of the case studies presented in this chapter describe subject projects, organizations, and technologies. Reflecting ATP's emphasis on demonstrating economic impact, many of them include substantial quantitative elements, including projections of social rates of return. Table 6–1 lists a selection of ATP's case studies on which this chapter is based. The main objectives and key features of the studies are shown.

This chapter is organized according to three major case-study objectives: modeling and estimating economic impacts, estimating project and portfolio performance using multiple cases and progress indicators, and explicating selected program features and exploring dynamics. The chapter emphasizes the approaches and models used to carry out the case studies; findings are presented only as they contribute to a fuller explanation of the underlying models or cases.

Economic Case Study of Individual Projects

The case studies illustrate the point made earlier that evaluation is an art as well as a science and a craft. Each researcher or team of researchers takes a somewhat different approach to creating a case study, depending on project particulars—

*Table 6–1. Ten of Sixteen Studies Featuring Case Study Represented**

STUDY (AUTHOR)	STUDY FEATURES: Descriptive emphasis	ATP's role discussed	Multiple projects covered	Case study combined with other methods	Quantified performance measures
Modeling and estimating the economic impact of projects					
Impacts of the Printed Wiring Board Joint Venture (Link)	Technology and organization	Yes	No	Yes	Short-term economic
Benefits of Medical Technologies (Martin et al.)	Modeling, technology, and application	Yes	Yes	No	Long-term economic
Controlling Dimensional Variation in Automobile Body Manufacturing (CONSAD)	Technology, application, and organization	Yes	No	Yes	Short-term and long-term economic
Impacts of Flow-Control Machining Technology (Ehlen)	Technology, application, and modeling	Yes	No	Yes	Short-term and long-term economic
Closed-Cycle Air Refrigeration Technology (Delta Research)	Technology, application, and modeling	Yes	No	No	Long-term economic
Status Reports: Estimating project and portfolio performance with multiple cases and progress indicators					
Status Report 1 (Long)	Technology and organization	Yes	Yes	Yes	Indicators
Status Report 2 (ATP)	Technology and organization	Yes	Yes	Yes	Indicators
Explicating program features and exploring dynamics					
Capital Formation and Investment in Venture Markets (Gompers and Lerner)	Organization	Yes	Yes	Yes	Description only

Table 6–1. (Cont'd)

STUDY (AUTHOR)	STUDY FEATURES: Descriptive emphasis	ATP's role discussed	Multiple projects covered	Case study combined with other methods	Quantified performance measures
Explicating program features and exploring dynamics (Cont'd)					
Interactions of ATP with State Technology Programs (Feldman and Kelley)	Organization	Yes	Yes	No	Description only
Information Infrastructure for Healthcare Focused Program (Lide and Spivack)	Technology and application	Yes	Yes	No	Description only

**Note:* Other studies using the case study method as a secondary method listed in Table 3–4, but not explicitly treated here, are by Austin and Macauley, 2000; Przbylinski, 2000 draft; Fogarty et al., 2000 draft; Liebeskind, 2000 draft; and Dyer and Powell, 2002.

objective timing of the study, market applications, data availability—as well as their research expertise, study budget, and research perspective.

The first group of case studies provides economic impact estimates for individual projects funded by ATP. These cases also provide descriptions of the technologies and the innovating organizations, the sources of economic benefit, and the role of ATP in the projects.

The first approach reported here was developed for application early both in ATP's history and in the life cycle of the surveyed projects. Lacking market observations on economic benefits at the time the studies were undertaken, the researcher took a novel approach to estimating minimum project benefits based on research cost savings. The second approach covered seven tissue-engineering projects, all aimed at providing improved medical treatment at lower cost. The team of researchers developed a method for estimating expected social economic return on public investment, using concepts from health care assessment to measure patient quality-of-life benefits in several of the cases. The third approach listed combined microeconomic estimation techniques with macroeconomic modeling to estimate national benefits from adoption of new automotive technology. The fourth approach focused greater attention on market research as a way to explore multiple target applications for the technology, emphasized combining estimated effects from multiple benefit streams, presented an explicit treatment of qualitative benefits in conjunction with quantitative estimates, and provided a more transparent exposition.

Each of these studies is unique, raising the standard evaluation question of how to generalize findings from case studies. Adding weight to this reservation is that, aside from the set of tissue engineering studies, each was a separate undertaking commissioned at a different time, and no attempt was made to establish a uniform set of questions, data collection procedures, or other uniform research protocols among the studies by different researchers. This decentralized approach was considered appropriate at the time the studies were commissioned as ATP was purposefully experimenting with different approaches and testing the analytical capabilities of contractors. Each of these studies was directed at a somewhat different question and in a different set of circumstances. Each of the studies represents a legitimate approach to the particular case and set of problems it tackled; in the aggregate, they highlight the flexibility as well as strengths and weaknesses of case studies within a larger portfolio of evaluation techniques.[148] The key features of each of this first group of studies are summarized in turn.

Estimating Minimum Benefits of New Technology in Terms of Research Cost Savings and Competitive Improvements

In its first competition in 1990, ATP funded five joint ventures among a total of 11 projects selected—several of them relatively large, five-year efforts. Eager to

[148] In recent years, ATP has commissioned additional sets of in-depth case studies for certain technology areas—similar to the tissue engineering set presented in the next section below. These studies are underway at the time of this report and include case studies of a set of photonics projects, carried out by Todd Watkins, Lehigh University, and a set of component software projects carried out by Research Triangle Institute.

learn more about how these early joint ventures were performing and to document results, ATP commissioned Albert Link, University of North Carolina-Greensboro, to evaluate three joint ventures near the midpoints of their five-year duration.[149] Each of the three projects represented an attempt by a group of U.S. companies within an industry sector—the printed wiring board (PWB) industry, the data storage industry, and the advanced display industry—to respond to foreign competition and enhance their industry's competitiveness through the development of a suite of "leap-frog" technologies. Subsequently, ATP focused on evaluation of the PWB project, and sponsored Link to update the analysis of the joint venture at project end.[150]

Link's Approach

Link used essentially the same approach in each of the case studies he performed: He described the industry, the technology, the nature of the collaboration, the major research tasks, the project's organizational structure, and the role of ATP. He also identified changes in the participating organizations and research plan as the project unfolded. Because of the early stage of the projects he investigated, Link focused on quantifying research cost savings from the collaboration and on changes in competitiveness, rather than on attempting to forecast benefits from the technology in use. In each case, he surveyed the participants to collect data needed to estimate impacts.

By examining the characteristics of the member companies, Link assessed the nature of the collaboration. For example, although the PWB joint venture is primarily a horizontal collaborative research arrangement, Link found that the members were actually not head-to-head competitors. This finding was important

149Albert N. Link, *Advanced Technology Program: Economic Study of the Printed Wiring Board Joint Venture after Two Years* (Gaithersburg, MD: National Institute of Standards and Technology, 1993); Albert N. Link, *Economic Study of the Joint Venture Project on Short-Wavelength Sources for Optical Recording after Three Years of a Five-Year Research Program* (Gaithersburg, MD: National Institute of Standards and Technology, 1994); and Albert N. Link, "Low-Cost Flat Panel Display Joint Venture [after Three Years of a Five-Year Research Program]," in *Evaluating Public Sector Research and Development* (Westport, CT: Praeger, 1996).

150Link, *Advanced Technology Program: Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End*, 1997.

because it helped explain why the joint venture members collaborated more fully and shared their research results more extensively than in cases where joint venture members were direct competitors.[151]

Data Collection

To collect data for the quantitative part of the case study, Link used a survey with three parts, and one with a counterfactual element. The survey part of the PWB case study was described in earlier in Chapter 5.

Link collected additional data by asking members of the project's steering committee—a management group made up of representatives from the participating organizations—to respond, in terms of the level of agreement/disagreement, to a set of ten statements. The statements describe the importance of the PWB joint venture to the company and the industry in terms of ability to refine manufacturing technologies and commercialize new scientific discoveries and technologies more rapidly and to improve competitive position.

Link collected qualitative information from members of the steering committee, who were asked to complete the following statement: "My company has benefited from its involvement in the PWB joint venture in such non-technical ways as ...". Also, they were asked to listen to a reading of the goals of ATP, and to indicate in response the degree to which they thought ATP goals had been fulfilled in their project.

The remaining data Link collected in support of the impact analysis related to effects from using the resulting technology. He asked members of the steering committee to estimate their own company's productivity gains traceable to using project outputs in their production. These data were sparse because the research was just concluding at the time of the study.

[151]In the case of the advanced display project, Link found that the joint venture members directly competed with one another, and that this pattern of competiton reduced their willingness to share research results.

Presentation and Interpretation of Results

Link used the collected data to provide estimates of minimum impact for the PWB joint venture, part of which are quantitative and part qualitative. To obtain an estimated minimum dollar value of the assistance provided by ATP, Link combined the various cost savings from efficiency gains in carrying out the projects as a joint venture. He counted costs savings only for that part of the research the companies said they would have pursued on their own without ATP, because otherwise they presumably would have incurred no research costs.

Table 6–2 summarizes direct impacts to member companies: research cost savings (a total of $35.5 million at project end), production cost savings ($5.0 million at project end), and indirect impacts on member companies (that is, increase in competitive position in world markets). It also shows partial spillovers to the PWB industry: 214 papers, 96 conferences, and increased competitive position for the U.S. industry as a whole. For comparison, the table brings forward the summary results of the earlier case study of the PWB project that Link performed two years into its five-year timeframe.

In addition to the results summarized in the table, Link pointed out potential value in the new capabilities the companies now have due to approximately half of the total of 62 project research tasks that were omitted from the cost savings calculation.[152] He also noted reduced cycle times for new project and process development and the presence of substantial technology transfer products providing pathways for the rest of the industry to benefit from the projects outputs. As is often the practice in case studies, Link included representative anecdotal responses from the companies about how they have benefited.

Link presented the results as "a conservative lower-bound estimate of the long-run economic benefits," and as "partial and preliminary estimates of project impacts." He pointed out that the bulk of production cost savings and performance gains would be realized in the future as the technology results diffuse and are more widely implemented.

[152]These were omitted from the calculation because there was no base from which to compute savings.

Table 6–2. 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		
Work years saved	$10.0 mil.	$24.7 mil.
Testing materials and machine time saved	$2.0 mil.	$3.3 mil.
Other research cost savings	$1.5 mil.	$7.5 mil.
Total	13.5 mil.	35.5 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 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 ATP.

Source: Link, *Advanced Technology Program; Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End*, 1997, p. 34.

Modeling Private and Social Benefits of a Set of Related Medical Technologies

Among the more ambitious and methodologically important case studies commissioned by ATP over its first decade was that conducted by economists at Research Triangle Institute (RTI) to estimate the economic impacts of a portfolio of seven ATP-funded projects in medical technology.[153] The study is valuable for several reasons. As an approach to portfolio assessment, it illustrated how use of a common, consistent methodology across a set of technologies within the same industry can be used to identify "project" or "technology" characteristics that affect the relative economic impacts of these projects. The study also showed how a formal model of relationships can be used to guide collection of information and data, and is notable for the care and detail with which it assessed ATP's programmatic objectives in the context of specific technologies. Finally, the study has value because, among those presented, it most explicitly links its design to the central analytical models and concepts used to articulate ATP's mission, while at the same time addressing "specific methodological challenges that have not been addressed in ATP's previous methodological development efforts."[154]

Study Objectives

The study had three objectives: First, to develop a methodology for estimating the expected social rate of return on public investment in ATP-funded projects with medical applications; second, to apply the model to all of the ATP-funded multiple-application tissue engineering projects funded by ATP between 1990 and 1996; and third, to estimate the composite social return and compare it with the composite private return for the set of cases. As shown in Table 6–3, four cases were performed in greater depth than the others.

153Sheila A. Martin, Daniel L. Winfield, Anne E. Kenyon, John R. Farris, Mohan V. Baal, and Tayler H. Bingham, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* GCR 97–737 (Gaithersburg, MD: National Institute of Standards and Technology, 1998).

154Ibid., pp. 1–2.

Table 6–3. Overview of ATP Projects Included in this Study

ATP PROJECT TITLE[A]	PROJECT SPONSOR	ATP AWARD Competition number	ATP AWARD Duration	ATP AWARD Funding level
In-depth case studies				
Human Stem Cell and Hematopoietic Expansion Systems "Stem Cell Expansion"	Aastrom Biosciences, Inc.	91–01	2 years	$1,220,000
Structurally New Biopolymers Derived from Alpha-L Amino Acids "Biopolymers for Tissue Repair"	Integra LifeSciences Corp.	93–01	3 Years	$1,999,000
Disease Treatment Using Living Implantable Microreactors "Living Implantable Microreactors"	BioHybrid Technologies, Inc. (lead company in joint venture)*	93–01	3 Years	$4,263,000
Treatment of Diabetes by Proliferated Human Islets in Photocrosslinkable Alginate Capsules "Proliferatd Human Islets"	VivoRx, Inc.	94–01	3 Years	$2,000,000
Brief case studies				
Fabrication Using Clinical Prosthesis from Biomaterials "Biomaterials for Clinical Prostheses"	Tissue Engineering, Inc.	92–01	3 Years	$1,999,000
Application of Gene Therapy to Treatment of Cardiovascular Diseases "Gene Therapy Applications"	Progenitor, Inc.	94–01	3 Years	$1,996,000
Universal Donor Organs for Transplantations "Universal Donor Organs"	Alexion Pharmaceuticals	95–01	3 years	$1,999,000

Note: Tissue engineering produces materials that can be used either to replace or correct poorly functioning components in humans or animals. Throughout this report we refer to each project by the abbreviated title listed below the full title.

* BioHybrid was approved for a 2-year no cost project extension.

Source: Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–13.

RTI's Approach to Estimating Benefits and Costs

RTI's approach was to build on Mansfield's model for estimating private and social rates of return, modifying it to take into account the specific forms of benefits generated by medical technologies. It also incorporated the evaluation and policy design precept implicit in Mansfield's work and made explicit by Jaffe: that because private sector R&D tends to generate social rates of return, the test of ATP's economic impacts are the social rates of return it generates above those likely to have resulted from private sector activities alone.

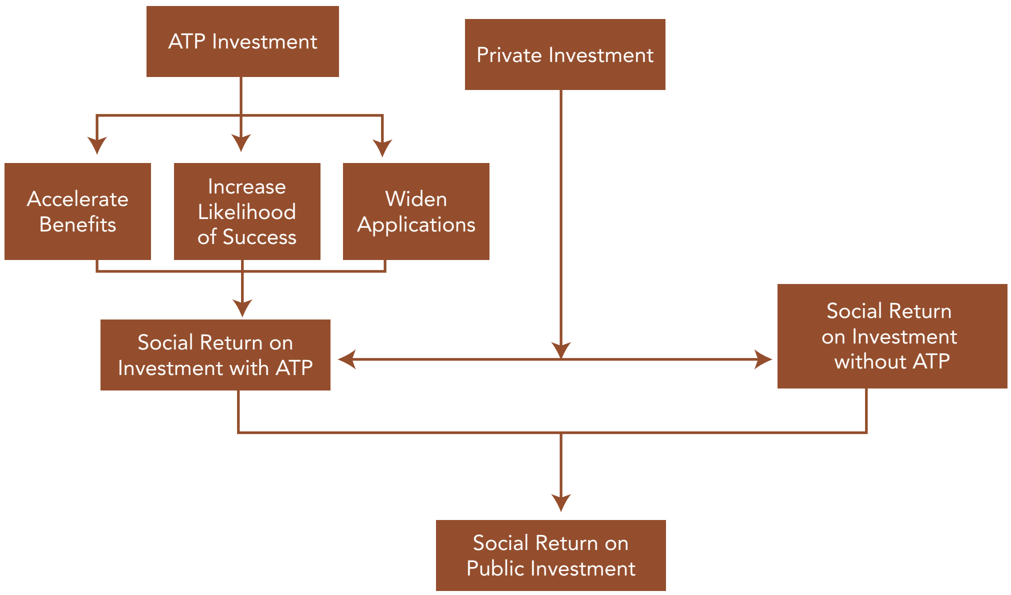
RTI modeled ATP funding of R&D projects as affecting the development of medical technology in three ways: (1) accelerating the technology's benefits (i.e., bringing benefits to the private sector, patients, and society sooner and for a greater number of years than without ATP funding); (2) increasing the likelihood of success (i.e., increasing the amount of R&D conducted and thereby the likelihood that a project will be technically successful); and (3) widening the scope of the project and enabling the company to apply its technology to additional diseases or patient populations. Figure 6–1 illustrates the model underlying the selection of relationships and variables for which information and data were collected.

Table 6–4 relates these differential benefits across tissue engineering projects to the effects of ATP funding. The single greatest source of differential effects was estimated to be acceleration by ATP of the rate at which a technology is brought to a marketable stage. Company officials involved in developing biopolymers for tissue repair, in RTI's words, reported that without ATP assistance the company might not have developed this technology at all or might have developed it so slowly that the market opportunity for it would have passed before it was ready for commercialization. In this case, the study assigned a 10-year advantage in estimating project benefits with ATP support.

RTI modified the Bass diffusion model[155] to estimate adoption of the new technologies. The rate of adoption was increased during the earlier period and decreased as the market potential was approached. RTI assumed that a newer

[155]Frank M. Bass, "A New Product Growth Model for Consumer Durables," *Management Sciences*, 15(5):215—227, 1969.

Figure 6–1. Elements Determining Social Return on Public Investment and Social Return on Investment



Estimation of each of the generic effects, in turn, represented construction of a set of scenarios detailing what was expected to happen because of ATP funding relative to what would have happened in the absence of the funding. Thus, for example, if it were assumed that ATP funding accelerated bringing a product to market by two years, the model assumes that the with-ATP innovation starts generating benefits two years earlier and has an economic life two years longer (and thus a higher net present value) than the same innovation produced without ATP funding.

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies*, 1998, p. 1–5.

technology would completely supersede each of the ATP-funded technologies after a 10-year period and models a cessation of diffusion at that time.

RTI separated net benefits estimation into those occurring in the medical technology sector and in the health care delivery sector. For the medical technology sector, net benefits included estimated change in revenues from sales of the

Table 6–4. Impact of ATP Funding on the Development of Medical Technologies for Seven Tissue Engineering Projects

ATP PROJECT	PROJECT ACCELERATION[A] (YEARS)	INCREASE IN THE PROBABILITY OF SUCCESS (PERCENT)	WIDENING OF TECHNOLOGY APPLICATIONS*
Stem Cell Expansion	1 to 2	9	None reported
Biopolymers for Tissue Repair	At least 10	171	Significant but not quantified
Living Implantable Microreactors	2	11	None reported
Proliferated Human Islets	3 to 5	2	None reported
Biomaterials for Clinical Prosthesis	2	1	None reported
Gene Therapy Applications	2	20	Some effects reported but not quantified
Universal Donor Organs	1 to 2	16	None reported

Note: Our model allows conceptually for ATP funding to widen the scope of a project. In practice, for the applications in this study, there was little or no impact in all but two cases, which we did not quantify.

*This is the number of years of acceleration reported by the ATP-funded companies. For the one to two year ranges, we used the lower number for our analysis. For the three to five year range, we used the midpoint of the range.

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–23.

new medical products and procedures, less investment and production costs incurred in bringing them to market, as compared with the displaced defender products and procedures; that is, the change in profits from having the new technologies. For the health care delivery sector, net benefits included reductions in the costs of health care and the value of increased health benefits to patients.

To estimate the value of health benefits, RTI adopted a concept called Quality Adjusted Life Year (QALY), developed in the field of healthcare to allow quantification of health changes in terms of the quantity and quality of life.[156]

[156]See George W. Torrance and David Feeny, "Utilities and Quality-Adjusted Life Years," *International Journal of Technology Assessment in Health Care,* 5: 559—575, 1989.

Where a year of life at full health is assigned a QALY value of 1.0, and death is assigned a value of 0.0, in between states are assigned QALY values between 0.0 and 1.0.[157] The QALYs must be translated into dollar values. The steps required in valuing per-patient changes in health outcomes and RTI's methodological approach at each step are summarized in Figure 6–2.

As noted, one of the contributions of the RTI methodology is that it offered insights into the sources of variation in rates of return across a portfolio of similarly directed technologies. As stated in the report, "Social returns to these projects can vary with respect to the number of patients treated, the value of the health benefits of the new technology, their impact on health care costs, and the probability of technical success."[158]

Data and Assumptions

Information on market potential, R&D expenditures, benefits to patients, and other variables necessary to compute social and private rates of return for each case was collected from a number of sources, including representatives from the companies receiving ATP funding. According to Martin et al.:

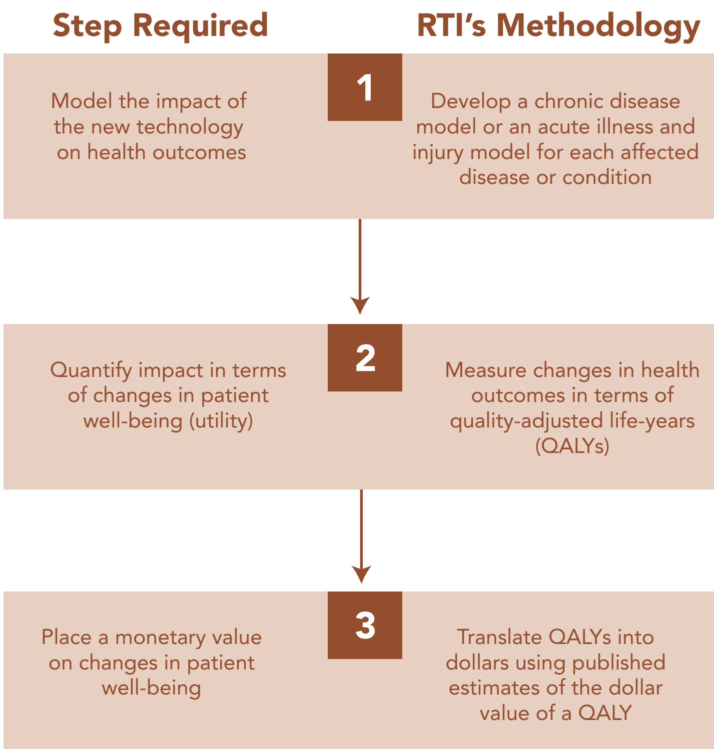
> The most important sources of information about each technology were representatives of the companies receiving ATP funding. We interviewed representatives of each lead company and, in some cases, also interviewed representatives of partner companies. We also talked with a number of physicians and consulted a variety of secondary data sources, including medical literature and statistical databases, to develop estimates of costs and benefits. (p. 1–14)

The inclusion of estimated benefits from health improvements was dependent on the researchers being able to find existing QALY values, because estimating them was beyond the scope of the project. These values have been developed for certain

157 For an account of the QALY technique in estimating net benefits of new medical technologies, see Andrew Wang, "Key Concepts in Evaluating Outcomes of ATP Funding of Medical Technologies," *The Journal of Technology Transfer* 23(2): 61–65, 1998.

158 Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–22. (Note that the report uses the page numbering system of chapter-page.)

Figure 6–2. Valuing Per-Patient Changes in Health Outcomes



Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–9.

health conditions and diseases from surveys of affected populations, such as cancer patients and diabetics, based on choices expressed by respondents; however, they are not available for every disease or condition. Where they found suitable QALY data, the researchers used the data to develop benefits from improved health outcomes. For example, the researchers found much of the data required for the model of health outcomes related to new treatments for diabetes from the Diabetes Control and Complication Trial (DCCT).[159] They found, for example, that blindness from retinopathy carries a QALY of 0.69; end-stage renal disease carries a QALY of 0.61; and lower extremity amputation, a QALY of 0.80. For illustration, Table 6–5 lists various QALYs for different health states and corresponding study source.

To determine the dollar value of the change in the patient's well being, RTI researchers estimated the economic value of a QALY based on willingness-to-pay values for avoiding illness and accidents taken from existing studies.[160, 161] They also drew probability data from existing studies, such as the probability of blindness given diabetes from the DCCT study.

Composite Private and Social Rates of Return

Table 6–6 summarizes the study's estimated expected social return on total investment and the expected social rate of return on public (ATP) investment for each of the ATP projects examined in the RTI study. It also shows the composite rate for all the projects taken together.

Based on these results, the authors concluded:

> ATP funding is responsible for inducing about 31% of the total social returns from all of these projects over 20 years. For the individual projects, the effect of ATP on social returns ranges from about 25% to 100% of the social returns. (p. 1–22)

Table 6–7 reports the composite private return on investment for the seven projects. Based on comparing the social and public returns in Figure 6–7 and the private returns in Figure 6–8, the authors concluded:

---

159 Diabetes Control and Complications Trial Research Group, "The Effect of Intensive Treatment of Diabetes on the Development and Progression of Long-Term Complications in Insulin-Dependent Diabetes Mellitus," *New England Journal of Medicine* 18:1468–1478, 1996.

160 Josephine A. Mauskopf and Michael T. French, "Estimating the Value of Avoiding Morbidity and Mortality from Foodborne Illnesses," *Risk Analysis* 11(4):619–631, 1991.

161 Michael J. Moore and W. Kip Viscusi, "Doubling the Estimated Value of Life: Results Using New Occupational Fatality Data," *Journal of Policy Analysis and Management* 7(3):476–490, 1988.

Table 6–5. Comparison of QALY Utility-Weights for Different Health States

HEALTH STATE	UTILITY WEIGHT	STUDY
Full health	1.00	Torrance and Feeny, 1989
Side effects of hypertension treatment	0.95–0.99	Torrance and Feeny, 1989
Kidney transplant	0.84	Torrance and Feeny, 1989
Lower extremity amputation	0.80	DCCTRG,* 1993, 1995, 1996
Mild shingles pain	0.73	Wood et al., 1997
Blindness	0.69	DCCTRG,* 1993, 1995, 1996
Severe menopausal symptoms	0.64	Daly et al., 1993
Chronic lung disease	0.63	O'Brien and Viramontes, 1994
Insulin-dependent diabetes	0.58	Burckhardt et al., 1993
Rheumatoid arthritis	0.52	Burckhardt et al., 1993
Severe angina	0.50	Torrance and Feeny, 1989
Anxious/depressed and lonely much of the time	0.45	Torrance and Feeny, 1989
Chronic obstructive pulmonary disease	0.38	Burckhardt et al., 1993
Mechanical aids to walk, needs help of another person to get out, and learning disabled	0.31	Torrance an Feeny, 1989
Dead	0.00	

DCCTRG stands for the Diabetes Control and Complicating Trial Research Group.

Source: Excerpted from RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 2–23.

The wide disparity between social and private returns indicates the importance of ATP incentives to the private sector to pursue these technologies. Because the social returns far outweigh the returns to the companies developing, commercializing, and producing these high-risk projects, the private sector may under invest in these kinds of high-risk projects. (p. 1–24)

Table 6–6. Social Return on Investment and Social Return on Public Investment: ATP Projects in Tissue Engineering for a Single Preliminary Application

ATP PROJECT	EXPECTED SOCIAL RETURN ON TOTAL INVESTMENT: NPV (1996 $ millions)	EXPECTED SOCIAL RETURN ON TOTAL INVESTMENT: IRR (percent)	EXPECTED SOCIAL RETURN ON PUBLIC (ATP) INVESTMENT: NPV (1996 $ millions)	EXPECTED SOCIAL RETURN ON PUBLIC (ATP) INVESTMENT: IRR (percent)
Stem Cell Expansion	134	20	47	21
Biopolymers for Tissue Repair*	98	51	98	51
Living Implantable Microreactors	74,518	149	17,750	148
Proliferated Human Islets	2,252	36	1,297	34
Biomaterials for Clinical Prosthesis	32,855	118	15,058	128
Gene Therapy Applications	2,411	106	945	111
Universal Donor Organs	2,838	91	783	92
Composite Rate for All Projects**	109,229	115	34,258	116

* For biopolymers, the two sets of figures are identical because all of the social return can be attributed to ATP investment.

**See notes to Table 6.5 in the original for an explanation of the derivation of the composite measure of return.

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies*, 1998, p. 1–22.

Limitations

As careful, systematic, and methodologically focused as the RTI study was, it still has limitations. Paramount among these, as with many of the case studies reviewed in this section, is that it is a projection of expected net economic benefits, not a measurement of observed benefits. None of the tissue engineering technologies covered in the RTI study had entered commercial use at the time of the study, although some were in clinical trials. In fact, at the time of the study, it had not yet been demonstrated fully that all would function technically as expected, thereby compounding uncertainty in the estimated outcome. Thus, there was a

Table 6–7. Composite Private Returns: ATP Projects in Tissue Engineering for a Single Preliminary Application

	NPV (1996 $ Millions)	IRR (percent)
Project returns	1,564	12
Increment attributable to ATP	914	13

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–24.

"shortage of *ex post* empirical data."[162] This limitation, clearly, was a function of the time at which the case study was done, and not a function of the case study method or the implementation of this case.

Another limitation of data rather than the model is the fact that the study only estimated patient benefits from improved health outcomes when there were pre-existing QALY data for the relevant medical conditions. Thus, the disparity in the size of net benefit estimates among the projects to some extent reflected the inclusion of patient health care cost, but not of patient health outcomes in several cases. Exercising the model for only one application of multi-use technologies is a choice reflective of budget limitations rather than a shortcoming of the model.

What most distinguishes this study is its explicit attention to methodological development; linkage to the multiple, attributed impacts of ATP funding, and formal ties to core theoretical constructs. Further, by analyzing all the projects funded by ATP within a single technological area, the study strengthened its ability to generalize results within that area.

[162]Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 1–2.

Estimating Market-Based Economic Impacts from Automotive Technology Combining Microeconomic and Macroeconomic Modeling

This section pairs two case studies: CONSAD Research Corporation's case study of dimensional control technology, the "2mm Project,"[163] and former economist at the National Institute of Standards and Technology (NIST) Mark Ehlen's case study of flow-control machining technology.[164] Although performed by different researchers, these two cases bear similarities. In both cases the first application of the multi-application technologies was to automobiles. Both entailed primarily vertically structured joint ventures, which bring together in some role supplier-innovators, universities, and large automobile assemblers. Both dealt with new manufacturing process technologies that offered quality/performance improvements. Both employed a micro-level examination of impacts arising from the technical characteristics of the project. Both attempted to link microeconomic modeling of firm- and industry-level impacts to macroeconomic modeling of national economic impacts.

The case studies have several important differences. The first case study was done on a much smaller budget, a shorter schedule, at an earlier time, on more of an experimental basis, and with less detail than the second. The first case study uses two, largely disconnected approaches: a microeconomic approach to estimate production and maintenance cost savings based on unit savings and current production volumes, and a macroeconomic approach to estimate total industrial output and employment changes, based on expert judgment about the increase in sales of U.S.-made vehicles due to technology-based quality improvements. In contrast, the second case study systematically built its model from firm level, to industry level, to the national level, integrating across the micro- and macro-parts of the analysis. Features of these two cases are discussed and compared below.

[163]CONSAD Research Corporation, *Advanced Technology Program Case Study: The Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing,* NIST GCR 97–709 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

[164]Mark A. Ehlen, *Economic Impacts of Flow-Control Machining Technologies: Early Applications in the Automobile Industry,* NISTIR 6373 (Gaithersburg, MD: National Institute of Standards and Technology, 1999).

Establishing Impact Expectations by Examining Technical Characteristics

Both of the case studies explained to the reader why and how the projects' technical accomplishments could logically be expected to yield benefits, an important part of building the case story. In the case of the 2mm technology, CONSAD researchers explained that U.S. auto assembly plants required a cost-effective method of reducing dimensional variation in auto body assembly, using the existing workforce. The project developed a new metrology-based process for improving the fit of discrete manufactured parts, with potential application to multiple manufacturing industries. Four types of direct benefits were expected from its application to automobile manufacturing: (1) decreased production costs, (2) decreased product maintenance costs, (3) improved product quality, and (4) reduced time required to launch new products or product models. Experimental implementation of the technology in five U.S. auto assembly plants at the time of the study provided CONSAD with estimates of unit cost reductions.

In the flow-control machining project, Ehlen explained how the multi-application technology increases the functional precision of cast-metal parts that carry fluids in interior passageways. Applied to auto engines, the improved precision can increase engine horsepower, increase fuel efficiency, reduce emissions, and reduce engine costs. Ehlen provided diagrams showing how the efficiency of combustion is improved. As in the previous case, performance was informed by actual data—in this case, from testing a prototype-working machine on engine manifolds. Ehlen related how the improved technical capabilities could potentially be deployed in the auto industry in alternative ways, affecting the resulting benefits. For example, in the face of fuel shortage, it could be applied in producing engines for all vehicles to decrease fuel consumption across the board. It could be used to meet increased Corporate Average Fuel Economy (CAFE) requirements. It could be used in some vehicle lines in order to sell other, less fuel efficient models, while still meeting overall the existing CAFE requirements. It could be used in specialty vehicles to increase horsepower. In other words, there are a variety of possible strategies for deploying the new technology.

Investigating the Role of ATP

Both of the case studies addressed the role of ATP as they considered why federal assistance was needed, particularly given that large end-user companies were present in both joint ventures. They came to much the same multi-reason conclusion about why the project would not likely have gone forward without ATP involvement. As Ehlen writes:

> Ford and GM are unlikely to unilaterally adopt a new process that has not been proven to work; the FCM [flow-control machining] processes are particularly challenging since both constitute a radical departure in finishing processes—manufacturing directly to functional performance. Ford and GM are also unlikely to directly collaborate on a new process, since they are direct competitors on routine business matters and have concerns about federal antitrust-law enforcement. They tend not to fund the research of their suppliers. The suppliers would not perform the research themselves; they generally do not have the capital to do extensive in-house research—particularly not high-risk research. University researchers are typically interested in doing their own research, not the research of a supplier to automakers, and are not able to self-fund the type of research. (p. 4)

CONSAD researchers emphasized the difficulties of achieving cooperation among industrial participants who frequently compete against one another, or forging a joint research undertaking among different members who "might realistically expect notably different returns from their involvement in the project."[165] In the judgment of the authors:

> It appears unlikely that (a) this complex joint venture could have been formed and (b) funding for the research project could have been coordinated without direct administrative and financial involvement by the federal government. (p. 10)

[165]CONSAD Research Corporation, *Advanced Technology Program Case Study: The Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing,* 1996, p. 10.

Modeling the Technology's Adoption by Auto Manufacturers

The two case studies differed considerably in their modeling of the take-up of each technology. Based on reported steady adoption of the 2mm technology by a growing number of assembly plants at the time of the study, CONSAD researchers assumed successful commercialization within the automobile manufacturing industry within a relatively short period of time.

In contrast, Ehlen included as a major part of his study the assessment of the likelihood that the automobile industry would implement the flow-control machining processes, outlining two implementation paths for estimating near-term and longer-term impacts. He used historical adoption models of similar fuel-efficiency enhancement by auto manufacturers in modeling adoption of the new processes. Figure 6–3 illustrates the adoption modeling. The horizontal portion of the heavy solid line shows the near-term conservative view that the processes would be adopted at an introductory level only, maintained for five years, and then dropped. The upward sloping portion of the line indicates the longer-term, more optimistic projection of a broader implementation at the historical adoption rate of fuel injection technologies, implemented over 20 years by 80% of the market.

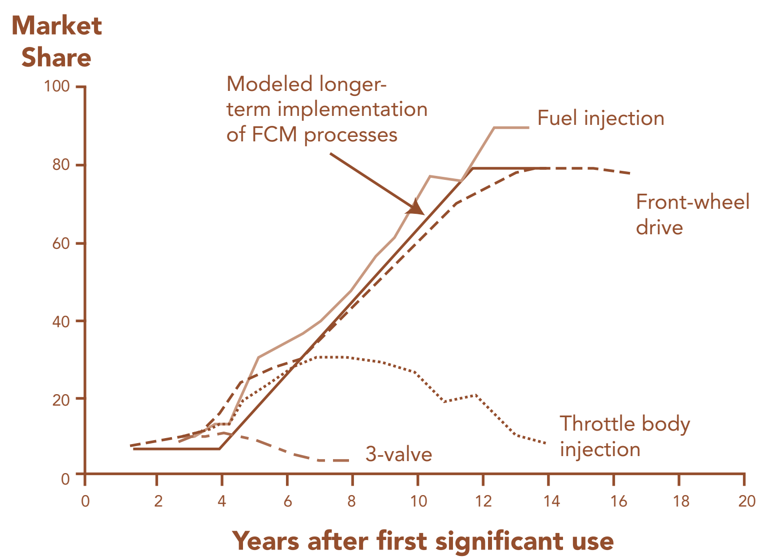
Data and Assumptions

Both case studies were limited in their assessment by the recentness of the technological innovation, and the absence of market-based data. As stated by CONSAD researchers:

> Because the technologies developed by the 2mm Project are new, their impacts on industrial production and economic activity are not yet revealed in the extant empirical data on industrial performance. (p. 17)

In the absence of market data, the CONSAD team turned to two expert panels for estimates of the magnitudes of impacts. The first group of experts was composed of individuals knowledgeable about the substance of the technologies and their likely impacts on costs and quality. The individuals interviewed were primarily university researchers, manufacturing engineers, and technicians and

Figure 6–3. Historical Adoption Rates of Technologies Enhancing Fuel Efficiency, and Implementation Rates used by Ehlen in the Case Study



Source: Ehlen, *Economic Impacts of Flow-Control Machining Technology: Early Applications in the Automobile Industry*, 1999, p. 54.

engineers involved with the initial implementation of project results at five automobile assembly plants. The second group was composed of individuals knowledgeable about the industries and markets in which the technologies would likely be used; these experts were asked for their assessments about the expected extent and rate of adoption of the technologies in specific industries and markets.

Limiting validation of the work of these two panels was the lack of detail provided due to concerns about confidentiality. "The individual sources of information and judgments, and information for individual plants and firms adopting technologies that have resulted from the 2mm Project are not cited because of the proprietary and confidential nature of the data about current and expected cost savings and expected product demands."[166] Similarly omitted in the study's report was the means by which the judgments of the two panels were put together. "The plausibility of the judgments provided by the two groups of experts has then been evaluated by examining the coherence among the judgments provided by the various experts in each group."[167] Thus, the CONSAD study lacked transparency.

Ehlen seems to have faced fewer obstacles in obtaining and citing industry and firm data due to company confidentially. In general, the data, assumptions, and step-by-step procedure are more transparent in Ehlen's study. Ehlen received close cooperation, particularly from the major innovator, Extrude Hone, who took a keen interest in the case study and seemed unusually willing to share data. CONSAD also received close cooperation from the companies in the joint venture it studied, but apparently faced more restrictions on the publication of data. Without cooperation from project participants and the ability to attribute data to sources, a researcher will have a difficult time conducting a detailed and replicable case study.

Using Macroeconomic Modeling in the Case Study

Both studies used macroeconomic modeling to estimate national impacts from using the technology in the auto industry. In fact, the major methodological fillip to these studies relative to other ATP case studies was the effort to scale up economic impacts through the use of a macroeconomic inter-industry model. They both used the REMI (Regional Economic Modeling, Inc.) model for this purpose.

The application of REMI in these two projects defined the limit of ATP's use of macro-economic modeling as an adjunct to case study over its first decade of evaluation. Attempting to use macroeconomic modeling to assess the impact of a project, or even an entire program, is controversial. The "noise" in a $10 trillion economy is likely to overwhelm the measures of a macroeconomic model of the U.S. economy. Yet, the REMI model, comprised as it is of regional components

[166]Ibid., p. 17.
[167]Ibid., p. 18.

and a set of structural equations linking inputs and outputs, prices, and consumer spending, offers the possibility of estimating project impact at the national level, provided the subject technology will have sufficient impact to show up at an industry-wide level and can be effectively captured in the model's variables and causal linkages. In both the case studies treated here, it was thought that the extensive participation of large auto manufacturers provided conditions that would allow REMI modeling to be used. But for most ATP projects it is unlikely that necessary conditions would be met, and a macroeconomic model would not be an appropriate evaluation tool.

The CONSAD study applied the REMI Economic and Demographic Forecasting and Simulation 53-Sector (EDFS–53) model in conjunction with analysis based on the input-output (I-O) tables of the U.S. Department of Commerce's Bureau of Economic Analysis. The model was used to estimate changes in industrial production and employment due to the projected increase in autos resulting from an increased combined market share of the participating U.S. auto manufacturers, based on expert opinion about the change in demand for U.S. assembled autos due to improved quality.

In contrast, Ehlen used a more detailed REMI model, and systematically built and integrated from the microeconomic modeling to the macroeconomic modeling. First, he estimated the impact on firms of near-term implementation over a five-year implementation path. Next, he estimated changes in industry performance and the change in annual sales for the three industry sectors involved in the supply of the technology. Finally, he used market quantities in the REMI analysis to estimate macroeconomic impacts. Table 6–8 summarizes the REMI findings for the year 2004, based on the assumed five-year, conservative implementation path.

Estimating Net Benefits from Multiple Applications of an Advanced Refrigeration Technology

Whereas the case studies presented in the two preceding sections each performed a benefit-cost analysis for the single most promising application of the technology, the case study presented in this section investigated multiple applications. Prepared by Thomas Pelsoci, managing director of Delta Research Company, the case study examined closed-cycle air refrigeration technology (CCAR), funded by

Table 6–8. Annual Impact on U.S. Macroeconomy of Near-Term, Five-Year Implementation Path: Year 2004

ITEM	"WITHOUT FCM PROCESSES" FORECAST	"WITH FCM PROCESSES" FORECAST	IMPACT (DIFFERENCE)
Gross domestic product ($ million)	$9,353,745	$9,353,887	$142
Manufacturing	1,926,180	1,926,407	227
• Durables	1,102,410	1,102,623	213
• Non-durables	823,770	823,784	214
Non-manufacturing	7,427,565	7,427,480	(85)
Employment (number)	138,775,300	138,775,300	0
Manufacturing	17,823,188	17,824,985	1,797
• Durables	9,873,558	9,875,191	1,633
• Non-durables	7,949,630	7,949,794	164
Non-manufacturing	120,952,112	120,950,315	(1,797)
Personal income ($ million)	8,661,460	8,661,656	196
Income tax revenues ($ million)	1,260,978	1,261,011	34

Note: Dollar concepts are in 1998 constant dollars.

Source: Ehlen, *Economic Impacts of Flow-Control Machining Technology: Early Applications in the Automobile Industry,* 1999, p. 46.

ATP in 1995.[168] The joint venture project was completed in 1999, and, after subsequent corporate product development efforts, yielded "a cost-effective system for delivering ultra-cold refrigeration in the -70ºF to -150ºF temperature range to food processing, volatile organic compound, and liquid natural gas applications."[169] The system uses environmentally benign dry air as the working fluid to replace harmful refrigerants.

168Thomas Pelsoci, *Closed-Cycle Air Refrigeration Technology for Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project,* NIST GCR 01–819 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

169Ibid., p. v.

This study has several features that make it a good example of an economic case study. It has a clear technical characterization of the technology and its state of development; an assessment of the functional capability of the technology; an analysis of potential markets; description of pathways to commercializing in those markets; an assessment of market demand; a straight-forward, transparent benefit-cost analysis with clear identification of data and assumptions; discussion of the counterfactual; estimation of both private and social benefits; and inclusion of qualitative benefits.

Attention to Test and Demonstration Results

Given the prospective approach of the benefit-cost analysis, the attention the study gave to results of tests and demonstration of CCAR in operation takes on added importance. When technical feasibility, in addition to market feasibility, is in question—as it was in several of the tissue engineering case studies examined earlier—project risk is substantially increased.[170] To address the question of CCAR's technical feasibility,[171] Pelsoci cited the conclusion of project participants that "CCAR met or exceeded all acceptance criteria and successfully demonstrated its technical feasibility." Thus, the technology has been demonstrated to work, freeing the researcher to focus on the question of whether it will be adopted, when, and for what uses.

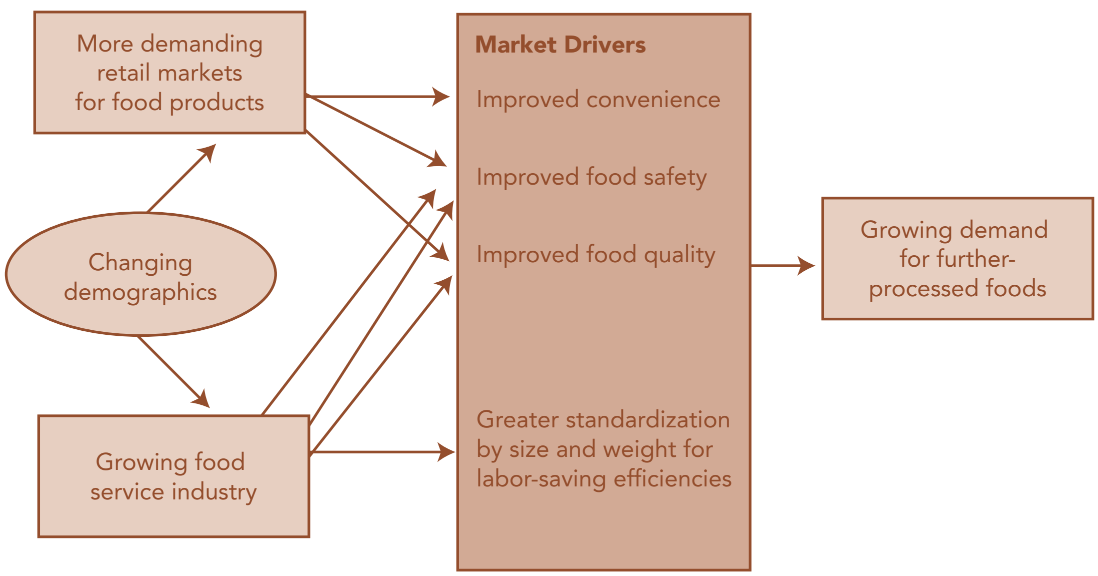
Market Assessment

The market analysis emphasized fact-finding and analysis of both primary and secondary markets for the technology. CCAR was termed a niche technology because it represented a cost-effective alternative only within the specified temperature range. Mechanical refrigeration provides cooling above the -70ºF range. Cryogenic refrigeration provides cooling below -70ºF, but its high cost may limit industrial applications.

[170] For example, if there is a 50% probability of achieving technical success, and a 50% probability of achieving commercial success, the combined probability of success is 25% (i.e., 0.50 multiplied by 0.50).

[171] Ibid., p. 6.

Figure 6–4. Market Drivers for the Further-Processed Food Industry



Source: Pelsoci, *Closed-Cycle Air Refrigeration Technology For Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project*, 2002, p. 12.

In the U.S. food industry value chain, the study identified "further-processed foods," a $131 billion market, as the targeted primary end market for the CCAR technology. As illustrated in Figure 6–4, the study identified key market drivers of this market segment.

The study related each of the market drivers to changing demographics. It explained how colder freezing is linked to more rapid freezing and in turn to higher quality, and how the CCAR technology provides an enabling technology for meeting market demands in the targeted primary market segment. It sourced two existing market studies by independent market research companies to assess the level of interest among food companies for the CCAR technology. It also relied on information gleaned from discussions with expert technical and sales staff at the joint venture companies, food industry associations, and food companies.

The study identified five promising pathways for marketing CCAR refrigeration services for food processing based on primary research and analysis completed during 2000 and early 2001: (1) replacing liquid nitrogen as a refrigerant, (2) replacing carbon dioxide as a refrigerant, (3) installing CCAR units at plants with expanding production, (4) installing CCAR units at newly constructed food plants, and (5) exporting into the overseas market. The study identified the four potential secondary markets for the CCAR technology shown in Table 6–9, and discussed the opportunities and barriers in these markets and explored the pathways to commercial acceptance. The study concludes that the residential, automotive,

Table 6–9. Secondary Market Opportunities for CCAR Technology

SECONDARY MARKETS	APPLICATIONS	COMPETING TECHNOLOGIES
Volatile organic compound recovery (50-ton CCAR units)	Refrigeration used to condense and separate volatile organic compound gases	Incineration and membrane adsorption
Liquid natural gas (200-ton CCAR units)	Replace marine diesel fuel	Compressed natural gas and low sulfur diesel
	Peak shaver in remote locations, without sufficient pipeline capacity	Compressed natural gas and expanded natural gas pipeline system
Pharmaceutical (10-ton CCAR units)	Freeze drying and controlling low temperature reactions	—
Petrochemical (200-ton CCAR units)	Storage and process refrigeration	Propane and other hydrocarbon refrigerants

Source: Pelsoci, *Closed-Cycle Air Refrigeration Technology For Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project*, 2002, p. 21.

and other warmer temperature applications are not likely to become viable markets for the CCAR technology.

Economic Analysis

The economic analysis portion of the study provided sufficient information about the model, assumptions, and data to make it easy to follow and replicate. Two scenarios were evaluated: a conservative base case and alternative "optimal" scenario. The optimal scenario was said to be consistent with the market studies and input from food processing and refrigeration industry experts, making it clear that the base case is conservative.

The study set a time period of 2002–2016 over which to forecast likely economic benefits. Like the RTI and Ehlen case studies, this case study separately identified benefits estimated to accrue directly to the joint venture partners and those estimated to accrue more broadly. Also like those cases, this case study applied a counterfactual analysis in deciding how to attribute estimated benefits from the CCAR technology to ATP.

Table 6–10 shows a summary of projected base case cash flows for application of the CCAR technology in the primary market, food processing. The contribution of each of the four different types of benefits within this market area can be seen.

Table 6–11 shows three estimated measures of public returns from ATP's investment in CCAR development: net present value (NPV), internal rate of return (IRR), and benefit cost ratio. Discounted at a 7% rate, the NPV was estimated at $459 million. The social return on total investment was not estimated. Because the study concluded that the technology would not have been developed without ATP assistance, the estimated benefits used to calculate public returns are presumably the same as would be used in calculating social benefits, but the costs presumably would differ.

Projected revenues accruing to the principal commercializing company in the joint venture were also presented. Discounted at a 9% rate, a rate selected by the researcher as a "likely proxy for the cost of funds of a major U.S. corporation," the present value of these projected revenues was $64.8 million. According to the researcher, profits could not be estimated due to the required information being

Table 6–10. Base Case Cash Flows from Improved Quality, Yield, and Production Rates and from Reduced Refrigeration Costs from Application of the CCAR Technology for Food Processing

Millions 2001 dollars

	CCAR REPLACEMENT OF MECHANICAL SYSTEMS			CCAR REPLACEMENT OF CRYOGENIC SYSTEMS	COMBINED CASH FLOW
	Cash flow from quality improvement	Cash flow from yield improvement	Cash flow from higher production	Cash flow from cost reduction	
1996					-0.8610
1997	INVESTMENT YEARS				-0.9150
1998					-0.6020
1999					0
2000					0
2001 e	0	0	0	0.832	0
2002 e	10.4	3.952	0.2184	2.496	0.8320
2003 e	31.2	11.856	0.6552	4.160	17.0664
2004 e	52.0	19.760	1.0920	5.824	47.8712
2005 e	72.8	27.664	1.5288	8.320	78.6760
2006 e	72.8	27.664	1.5288	8.320	110.3128
2007 e	72.8	27.664	1.5288	8.320	110.3128
2008 e	72.8	27.664	1.5288	8.320	110.3128
2009 e	72.8	27.664	1.5288	8.320	110.3128
2010 e	72.8	27.664	1.5288	8.320	110.3128
2011 e	72.8	27.664	1.5288	8.320	110.3128
2012 e	72.8	27.664	1.5288	8.320	110.3128
2013 e	72.8	27.664	1.5288	7.488	109.4808
2014 e	62.4	23.712	1.3104	5.824	93.2464
2015 e	41.6	15.808	0.8736	4.160	62.4416
2016 e	20.8	7.904	0.4368	2.496	31.6368

Source: Pelsoci, *Closed-Cycle Air Refrigeration Technology For Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project*, 2002, p. 31.

Table 6–11. Base Case Net Present Value, Internal Rate of Return, and Benefit Cost Ratio (Calculated from the Cash Flows in Table 6–10) for the CCAR Technology

	REPLACING MECHANICAL SYSTEMS			REPLACING CRYOGENIC SYSTEMS	COMBINED ECONOMIC IMPACT
	Economic impact of improved quality	Economic impact of improved yield	Economic impact of faster production	Economic impact of reduced cost	
Net present value ($ million)	$301	$113	$4	$33	$459
Internal rate of return	—	—	—	—	83%
Benefit-to-cost ratio	—	—	—	—	220:1

Source: Pelsoci, *Closed-Cycle Air Refrigeration Technology For Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project*, 2002, p. 32.

proprietary. Nevertheless, the information provided was sufficient to conclude that the public return is much greater than the private return.

Qualitative Benefits

At the time of the study, which was completed in early 2001, Pelsoci did not consider all the identified benefits of using CCAR technology to be quantifiable within the scope and budget of the study. He identified and discussed six additional categories of benefits, not included in the economic measures, but listed in Table 6–12.

It is typical that researchers encounter difficult- or impossible-to-measure effects when conducting economic case studies. But this does not mean the effects are unimportant. The approach used by Pelsoci in the illustrative case identifies and describes difficult-to-quantify effects qualitatively rather than ignoring them. The qualitative treatment reminds the reader of the effects not captured by the quantitative economic measures. In some cases, the study sponsor may wish to add

Table 6–12. Additional Qualitative Benefits from Using the CCAR Technology

- ✓ Improved food safety in the food processing industry due to an accelerated rate of cooling through the "danger zone" that produces public health risks from food-borne bacteria
- ✓ Improved food safety and reduced operating costs in the food service industries
- ✓ Reduced diesel emissions from hauling liquid nitrogen and carbon dioxide from avoiding the need to haul cryogens from production plants
- ✓ Reduced diesel emissions from ocean-going vessels by using CCAR refrigeration for dockside liquid natural gas facilities and replacing marine diesel fuel with liquid natural gas
- ✓ Cross-industry knowledge diffusion
- ✓ Enhanced organizational capacity by joint venture partners

Source: Compiled from Pelsoci, *Closed-Cycle Air Refrigeration Technology For Cross Cutting Applications in Food Processing, Volatile Organic Compound Recovery, and Liquid Natural Gas Industries, Economic Case Study of an ATP-Funded Project*, 2002.

resources to attempt further quantification. For example, techniques from health economics might be used to quantify the value of increased food safety.

Project and Portfolio Assessment Using Multiple Cases Studies with Uniform Collection of Key Indicator Data

While realizing the impracticality of performing in-depth case studies of every project, NIST and ATP management wished to harness the power of the case study for more projects and in a more systematic way. They wanted to develop a practical, cost-effective approach that would achieve 100% portfolio coverage to avoid selection bias, present each project story, consistently provide performance measures pertaining to the various dimensions of ATP's mission, and begin implementation immediately.

The result was a new evaluative product, known as Status Reports. Status Reports feature short descriptive narratives, combined with the consistent compilation of key output and outcome data. Each completed ATP project has been the subject of a status report several years after its completion. By aggregating the uniformly collected data, and by using the data in the ATP's composite performance rating system to score project overall performance (described in Chapter 8), ATP extended application of the case study method in ways to make it a more powerful tool for managing projects and a complex program, and answering a multitude of stakeholder questions. The second group of projects listed in Table 6–1 is the subject of this section.

To write the case studies of completed projects, analysts accessed ATP project records; used Business Reporting System (BRS) data when available; conducted telephone interviews with company representatives; conducted interviews with ATP project managers; searched company websites; used data collected by the U.S. Patent and Trademark Office; searched academic, trade, and business literature; searched news reports; viewed filings at the Securities and Exchange Commission; and used business research services, such as Dun and Bradstreet, Hoover's Online Company and Industry Network, and CorpTech. They also took into consideration previously prepared in-depth project studies featuring economic analysis. The project's lead company and ATP's staff are asked to review each of the individual project write-ups for accuracy.

ATP's First Published Collection of Status Reports

ATP's first collection of status report was published in 1999 and was prepared by William F. Long, Business Performance Research Associates, Inc.[172] The report included case write-ups for the first 38 completed projects, a summary overview with aggregate statistics, and a brief treatment of terminated projects, that is, projects ended prior to completion. Featured in each case study, in an easy-to-locate text box, as illustrated below for one project is a summary of the key information uniformly compiled for all the projects.

[172] William F. Long, *Performance of Completed Projects, Status Report 1,* NIST Special Publication 950–1 (Gaithersburg, MD: National Institute of Standards and Technology, 1999).

Excerpt from the Status Report for Diamond Semiconductor Group's Project to Lower the Cost and Improve the Quality of Computer Chips

Project:

To develop a novel approach for introducing dopants—substances that alter the electrical properties of semiconductor materials—into large semiconductor wafers to enable faster, less-costly fabrication of larger wafers with smaller, more-densely packed components.

Duration: 3/1/1993–6/30/1994
ATP number: 92–01–0115

Funding (in thousands):

ATP	$1,326	77%
Company	393	23%
Total	$1,719	

Accomplishments:

DSG developed broad-beam ion-implantation technology (now embodied in Varian's SHC80 Serial High-Current Implanter) that successfully implanted the first commercially viable 300-mm semiconductor wafer. The new technology doubled the existing industry-wide mean time between failures and provided additional ways to increase the quality and reduce the cost of chip fabrication. The company:

- received two patents for technology related to the ATP project:
  - "Compact High-Current Broad-Beam Ion Implanter" (No. 5,350,926: filed 3/11/1993, granted 9/27/1994), and
  - "High Speed Movement of Workpieces in Vacuum Processing" (No. 5,486,080: filed 6/30/1994, granted 1/23/1996);
- applied for two additional patents for technologies related to the ATP project;
- licensed the technology developed during the ATP project to Varian, which incorporated it in its SHC80 implant system and is actively selling the equipment to commercial customers; and

- licensed its technology to Mitsui Electronics and Shipbuilding for a flat-panel display application, after U.S. companies declined the licensing opportunity. DSG used $6.1 million from Mitsui to develop a 650-mm flat-panel component for displays. In 1997, Mitsui signed its first contract to supply the displays to a customer.

Commercialization Status

The technology has been commercialized in one application and is very near commercialization for a second application. Chip manufacturers using the Varian SHC80 implant system (which incorporates the technology) are producing larger (300-mm) wafers than before (200-mm) and making them faster, with higher quality and at lower cost.

Outlook

The outlook is excellent. Varian is already selling semiconductor fabrication equipment that incorporates the new technology, and a flat-panel display application is under way. The technology generates cost savings not only for companies using it to make computer chips but also for those who ultimately buy the chips and the products containing them. The benefits directly captured by DSG will likely be only a small fraction of the total net benefits the technology generates for the economy.

Company:

Diamond Semiconductor Group, LLC (DSG)
30 Blackburn Center
Gloucester, MA 01930

Contact: Manny Sieradzki

Phone: (978) 281-4223

Number of employees: 9 at project start, 25 at the end of 1997

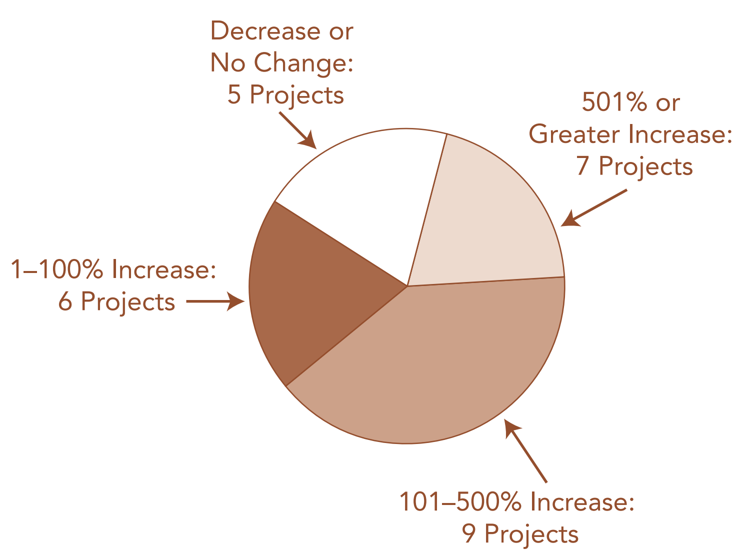
Informal collaborator: Varian Associates Inc.

Source: Long, *Performance of Completed Projects, Status Report 1,* 1999, p. 61.

In addition to the informational categories shown in the box, the narrative account of each project included an account of the role played by ATP. The report's overview provided aggregate statistics on the characteristics of the 38 projects, the gains in technical knowledge, dissemination of new knowledge, and progress in commercializing the new technologies. For example, of the first 38, 15 had patents granted and 23 did not; 42% had published or presented papers and 58% had none. Figure 6–5, drawn from Long's report, shows how employment changed at 27 small companies proposing to ATP as single applicants. Because these were for the most part extremely small, startup companies, dramatic increases in employment may signal project success and further progress.

Table 6–13 shows summary results of ATP's role. Two-thirds of the companies responding said they would not have proceeded without ATP funding; the rest said they would have proceeded but with a delay ranging from 18 to 60 months.

Figure 6–5. Distribution of 27 Completed Projects at Small, Single Applicant Companies by Percentage of Employment Change



Source: Long, *Performance of Completed Projects, Status Report 1,* 1999, p. 14.

Table 6–13. ATP's Role

WOULD HAVE PROCEEDED WITHOUT ATP FUNDING	NUMBER OF PROJECTS	PERCENT
Yes, but at a slower pace, with delay of	11	34%
• 18 months	4	
• 21 months	3	
• 24 months	3	
• 60 months	1	
No	21	66%
Total	32	

Source: Long, *Performance of Completed Projects, Status Report 1,* 1999, p. 15.

Taking the combined costs of the 38 completed projects and 12 projects that terminated during the same period, Long asked, "For its investment of $74.0 million, what has the public received, or is likely to receive, in return?"[173] Indicating that it was beyond the scope of his study to estimate returns for the entire portfolio of 38 projects, Long turned for answers to the three projects in the group for which "detailed estimates have been calculated by other researchers." These three included two of the projects from RTI's set of tissue engineering studies—Aastrom Biosciences' Stem-Cell Therapy Cost Reductions and Tissue Engineering's New Materials to Repair Damaged Ligaments and the project studied by CONSAD Research—the Auto Body Consortium's project on dimensional control for higher quality car bodies. Long concluded:

> The value of the projected benefits resulting from the ATP contribution in just the three ATP projects ...would greatly exceed total ATP costs to date. ...Based on the investigations of projects conducted for this study, considerable evidence suggests that others among the 38 projects are also quite promising in terms of their future benefits potential. (p.18)

[173]Ibid., p. 16.

ATP's Second Published Collection of "Status Reports"

ATP recently extended its published collection of status reports to include 50 completed projects, an updated overview that provided a new project rating system built on the case study data, the addition of patent trees, and a more extensive treatment of terminated projects.[174]

Table 6–14 summarizes the output and outcome data collected for the status reports. The informational categories were selected to measure project progress toward achievement of the major ATP goals: (1) adding to the nation's science and technical knowledge base—hence, information on awards by outside organizations for technical achievements, publications, presentations, and patents filed and granted; (2) disseminating the knowledge to others—a goal also furthered by publications, presentations, and patents, as well as by distribution (and reverse engineering) of commercialized products and processes, collaborations, and publicity value of awards; and (3) commercializing the technology in new and improved products and processes—signaled by attraction of capital for commercial activities, employment growth, commercialized products and processes on the market or expected soon; and future prospects. The informational categories included both outputs (e.g., publications and patents) and outcomes (e.g., commercial products).

The diverse output and outcome data collected for the completed projects are interesting and informative in their disaggregated form. They are more informative when analyzed statistically in an aggregated form, such as X percent of projects had resulted in commercialized products or processes two years after project completion. Nevertheless, it is difficult to gain a sense of how projects are performing overall when looking at nine sets of data linked to three aspects of mission. To provide a clearer assessment of performance on an experimental basis, the second volume of status reports featured a new rating system that scores projects based on a weighted composite of the nine types of data listed in Table 6–14. Called the Composite Performance Rating System (CPRS), it is a system that assigns 0 to 4 stars to each project on the basis of the composite of

[174] Advanced Technology Program, *Performance of 50 Completed Projects, Status Report 2,* NIST Special Publication 950–2 (Gaithersburg, MD: National Institute of Standards and Technology, 2001).

Table 6–14. Status Report Data

- ✓ Awards by outside organizations to recognize technical and scientific achievements
- ✓ Awards by outside organizations to recognize business acumen of small, usually rapidly growing companies
- ✓ Patents filed by project participants, granted and not yet granted
- ✓ Publications and presentations by project participants
- ✓ Collaborative activity of project participants
- ✓ Attraction of additional capital to take the technology further
- ✓ Employment gains by small-company award recipients
- ✓ Products and processes in the market or expected soon
- ✓ Analysts' outlook assessment for the technology as carried forward by the project participants and their collaborators

the uniformly compiled output and outcome data in the table.[175] The CPRS is presented in more detail in Chapter 8.

Additional Status Reports in Preparation

The coverage of the next volume of Status Reports, according to ATP staff, is targeted at 100 completed projects.[176] As the number of projects covered has grown, and the number of analysts performing the studies has also grown, the need for a set of data collection worksheets, and more rigor in assuring continued consistency in data collection, is apparent. Data templates are being used to guide preparation of the next batch of completed cases. In addition, a database has been developed that contains records for the first 50 projects, to which can be added data for future cases.

[175]For a fuller treatment of the CPRS, see R. Ruegg, *A Composite Performance Rating System for ATP-Funded Completed Projects*, NIST GCR 03–851 (Gaithersburg, MD: National Institute of Standards and Technology, 2003).

[176]KPMG Corp., (now BearingPoint) is preparing the next group of studies in the Status Report series. Information on the coverage of the next release was provided by Stephanie Shipp, Director, Economic Assessment Office, ATP.

These advances in the use of case study for ATP—extending it to all completed projects, providing a common format, capturing data consistently that relate to achievement of ATP's goals, aggregating the data across output and outcome categories, and using it to develop a composite rating—have given ATP a valuable new evaluation product built on case study, free of selection bias and useful for reporting portfolio performance.

Explicating Program Features and Exploring Program Dynamics

The following three studies, the last group in Table 6–1, illustrate the multiple and flexible uses of the case study method to explicate specific program features. They illustrate how case studies can be used in conjunction with survey, analytical, or empirical work. They also show how case studies can be stand alone reports on specific program elements not covered in larger studies, as in the Lide-Spivack account of the bottom-up processes that shaped ATP's selection of a technological area for focused program competitions.

Financing Needs of High-Tech Startups

The case study portion of the Gompers-Lerner project was based on public documents and on interviews with seven Boston-area companies that received ATP awards, and covered the period from the firms' establishment through fall 1997 when the case studies were completed. The companies span the industries of biotechnology, electronics, and software development. ATP's intended purpose in funding the case studies was primarily to learn how and why the companies sought funding from ATP, and the role that the funding played. The authors also saw the seven cases as a source of information for formulating general recommendations for improving the program.[177]

Each of the seven case studies was divided into three sections. The first section provided a brief profile of the company's technology, market focus, major

[177] More often, the business case study method used by Gompers and Lerner is seen as a source of information to formulate recommendations for improving the subject companies rather than the government program that provided financial assistance.

milestones, and financial history. Special emphasis in this section was placed on factors that could affect how the company completed and later commercialized its ATP-funded research. The second section described the company's ATP-sponsored project and examined the overall impact of ATP funding on the company. Among the topics recounted in this section were unanticipated research challenges, eventual project outcomes, the effect on the company's research agenda, and the interplay between ATP grants and other public and private funding sources, although all of these topics were not covered in every case. The third section in the case histories described the company's then current objectives (as of 1997), future plans, and recent developments.

Gompers and Lerner cited the case studies as evidence that ATP has had a substantial impact on the R&D activities of its awardees. They concluded that most of the company representatives interviewed felt strongly "that they could not have pursued their particular research challenges as quickly or as thoroughly without the ATP."[178]

Combining State and Federal Programs to Advantage

Recognizing the mutually reinforcing role of state programs with its activities, in 1996, ATP entered into a non-financial memorandum of understanding with the Science and Technology Council of the States, designed to foster cooperation in outreach, technical and business assistance to applicants, and to facilitate the formation of joint ventures. Another interplay between ATP and the state programs occurs through university involvement in ATP projects. Between 1990 and September 2002, universities were research partners in 336 of the 642 projects funded by ATP. There are 166 different universities and 589 instances of their participation. Many state-supported universities provided critical research expertise and specialized laboratory facilities to companies that had won ATP awards. In turn, ATP funding indirectly augmented state funding for university-based research. To better understand how its activities meshed with those of the state programs, ATP commissioned a series of case studies of the firms that received support from both ATP and one or more state governments.

[178]Ibid., p. 39.

The four case studies were reported in volume 2 in *Reinforcing Interactions between the Advanced Technology Program and State Technology Programs,* by Feldman, Kelley, Chaff, and Fracas. The four subject companies were all technology-pioneering companies, defined as "new enterprises that from their inception were intent on developing and eventually commercializing new technologies."[179] A singular feature of such firms is that in addition to the typical set of problems associated with startup businesses, they have to invest in research and attract patient investment capital willing to support the development of a technology that may be years away from generating any revenues for the firm. This definition was employed to more precisely match the type of firm that was eligible for ATP support with the otherwise larger set of firms which would have been eligible for support under the wider latitude of eligibility criteria found across state programs.

Other differences between ATP and state programs were noted in the report. Central to these differences was that "as a program of the federal government, ATP is concerned with the development of technologies that benefit the nation as a whole." Thus, an ATP project that led to the development of a new technology successfully commercialized by a U.S.-based firm and that generated spillover benefits would be considered a success, even though one or more firms participating in the original ATP project may not have directly benefited. "By contrast, to a state program intent on developing new businesses, success is largely measured in terms of the success of the individual firm and its growth within the region."[180]

The study focused on the following questions: What state-provided assistance and programs do technology pioneers use, especially in the early stages? What kinds of linkages do technology pioneers have to other businesses and universities in the region? Are these linkages related to the resources needed by the company to carry out its own R&D, or are they important for bringing the technology to market and use by potential customers?

---

[179] Feldman et al., *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs,* 2000, p. iii.

[180] Ibid., p. 3.

Selection of the four cases was based on recommendations of state technology program officers and the staff of ATP's Economic Assessment Office. The four firms in the study—HT Medical Systems, SAGE Electrochromics, CuraGen, and AviGenics—were ATP award recipients between 1992 and 1998. The firms were located in four states—Maryland, New Jersey, Connecticut, and Georgia, respectively—but in fact, had drawn on program resources in a total of eight states. In each case, the study identified the stage of development of the company when it received assistance from a state government, the form of the assistance from state agencies and public universities, and how the assistance dovetailed with the federal government's support of the R&D activities of these companies.

Conduct of the case studies required the cooperation of each company and the state agencies that had provided the assistance. Interviews with company principals, ATP program managers, officials at state development agencies, internal company documents, company prospectuses, and other documents in the public domain provided most of the information and data used to construct the case histories.

Although limited in number and not a random selection of all potential ATP cases, taken together the four case histories highlighted several important ways that ATP and state programs augment each other. Consistent with the underlying rationales of federal and state programs, the federal government played the largest direct role in funding R&D activities in all four cases, while state programs tended to support each firm's R&D activities through university-based programs. State programs also tended to fund more downstream commercialization activities by enabling the companies to obtain access to specialized laboratory facilities and research capabilities of public universities, and by providing seed capital.

Explaining and Promoting a Program Area: ATP's Information Infrastructure for Healthcare Focused Program

Bettijoyce Lide and Richard Spivack, both of ATP, used a case study approach to report on the specific history of ATP's Information Infrastructure for Healthcare (IIH) Focused Program. The report provides insights to ATP's external stakeholders, including both the executive and legislative branches, and to prospective applicants for ATP awards about ATP's "bottom-up" decision-making processes.

Over the course of its history, ATP has employed a mix of competition mechanisms. From 1990 through 1998, it held General competitions open each year to all technologies. From 1994 through 1998, it awarded most of its funding through a series of 30 focused program competitions, "in which a suite of projects was funded to mobilize technology to address a particular problem."[181] Starting with fiscal year 1999, ATP adopted a hybrid form of competition "in which ATP performs its outreach with industry much as it did under focused program competitions, but with a single competition open to all...."[182]

Lide and Spivack explained step-by-step how ATP's IIH program was developed, from a call for white papers from the research community to the final scoping and approval of the focused program internally. They reported the technical and business goals of the program, and described the envisioned program as having a pyramid structure with infrastructural development technologies comprising the program's base, user interface and efficiency enhancement technologies expected to be added next, and healthcare specific technologies to be developed last. In fact, projects of each kind were funded in each of the focused program's competitions.

The authors used the program case study to reach out to the focused program's community to allay concerns or uncertainties arising from an upcoming change in ATP's competition structure to eliminate focused programs.

Summary of ATP's Use of the Case Study Method

The studies reviewed in this chapter have illustrated the breadth and flexibility of the case study method as a means of evaluating the impacts of a project and of communicating a program's features, activities, and impacts to multiple

---

[181]Bettijoyce Lide and Richard N. Spivack, *Advanced Technology Program Information Infrastructure for Healthcare Focused Program: A Brief History,* NISTIR 6477 (Gaithersburg, MD: National Institute of Standards and Technology, 2000), p. 1.

[182]Ibid., p. 1.

audiences. Case studies have helped ground ATP's legislative mandates and program language in the operations of specific firms, industries, and research performers, thus making possible a clearer sense of the public interest served by the program. Case studies have highlighted in the context of specific firms the critical role that ATP funding has played in offsetting difficulties many firms had in obtaining venture capital or other capital to launch high-risk R&D projects. They have described the workings of joint ventures, as well as ATP's bottom-up process for identifying focused program areas when ATP was using both focused and general competitions. They have detailed ways that ATP made operational key methodological and analytical concepts described in Chapters 2 and 4, such as counterfactual designs and social savings models, while focusing attention on challenges associated with converting non-market outcomes into measures amenable to impact analysis.

The reports covered in this chapter also have illustrated the limitations of the case study method. Some of these limitations, particularly the difficulty of generalizing from single cases, are characteristic of the case study methodology. Others relate to the confidential and proprietary nature of the data sought from the firms that were the ATP awardees. Still others relate to the specific heuristic use made of case studies in the early period of ATP's evaluation program. Several of the case studies reported were designed to assess the feasibility of specific analytical techniques to estimate economic impacts; they were conducted early in the life cycle of ATP awards, typically prior to introduction of commercial products. Thus, most of the ATP economic case studies represent forecasts, not reports on realized outcomes.

The chapter also has introduced two approaches for increasing the ability to generalize from case studies to portfolio performance. One approach is to use a common method for in-depth analysis of similar technologies as RTI did in assessing the ATP-funded tissue engineering projects. A second approach is to use a common study template to collect key indicator data for all completed ATP projects and analyze the results statistically, as in the case of ATP's Status Reports.

The chapter has shown the versatility, power, and limitations of the case study method. The case study method is a mainstay of evaluation because it tells an easily understood story complete with characters, goals, difficulties, and results. Moreover, it can tell the story in an interesting and memorable way, and provide extensive detail that may be useful in formulating theories and hypotheses and laying the groundwork for further evaluation, including economic analysis. Case study is a particularly useful evaluation method for making complex scientific research and technology development projects accessible to a wide audience.

CHAPTER 7

Econometric/Statistical Method

Econometric/statistical analysis methods allow researchers to test the strength of economic relationships and to understand the range of variability in the estimates. As explained in Chapter 2, the strength of these methods is that they can provide more statistically defensible evidence about expected cause-effect relationships than most other evaluation methods. For this reason, econometric/statistical analysis methods hold particular value for ATP, which seeks to determine cause-effect relationships that underlie its program, and to answer pressing stakeholder questions about the program's effects on firms, industries, technological innovation, the U.S. innovation system, and the national economy.

In practice, these methods are data-intensive. Considerable effort is often required to obtain, array, and adjust the data that will be used to test the hypothesized relationships. The tasks involved in data collection and adjustment are not only expensive and time consuming, but can also involve numerous decisions and assumptions that significantly affect findings. Often it can be difficult to make the resulting analysis sufficiently transparent to those whose actions may be guided by the findings. A noteworthy aspect of several studies described here is the authors' candor in acknowledging that data were not obtainable to test certain models, that findings are tentative, that sample sizes were small, or that the time period studied was short. These self-assessments are reflective of the exploratory nature of ATP's use of the econometric/statistical analysis method.

The chapter is organized around the key questions that the studies were intended to answer. Table 7–1 lists eight studies commissioned by ATP that in this chapter illustrate the use of econometric/statistical methods in evaluation. The table provides a quick reference to study purpose and techniques used. While the presented studies illustrate specific econometric techniques, they in no way provide comprehensive coverage of this broad topic.

*Table 7–1. Eight of Ten Studies Using Econometric/Statistical Methods Represented**

STUDY/AUTHOR	PURPOSE	TECHNIQUES USED
Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect (Feldman and Kelley)	Testing hypotheses, including ATP's leveraging effects on R&D funding	Multivariate regression analysis; Tobit estimators
R&D Policy in Israel: Overview and Lessons for the ATP (Griliches, Regev, and Trajtenberg)	Measuring effects of government technology programs on firm productivity	Cobb-Douglas production function
R&D Spillovers, Appropriability and R&D Intensity: A Survey-Based Approach (Cohen and Walsh)	Testing the effects of appropriability and knowledge flows on innovation	System of simultaneous equations linking dependent variables to firm and industry level economic variables
Universities as Research Partners (Hall, Link, and Scott)	Investigating roles and effects of universities in ATP-funded projects	Multivariate regression analysis; Probit and Tobit estimators
Public-Private Partnering and Innovation Performance Among U.S. Biotechnology Firms (Kogut and Gittleman)	Investigating effects of public-private partnerships on innovation performance of firms	Predictive models using a negative binomial regression estimation technique
The Role of Knowledge Spillovers in ATP Consortia (Mowery, Oxley, and Silverman)	Testing hypothesized relationships between consortia and inter-firm spillovers	Models for testing hypotheses
Program Design and Firm Success in the Advanced Technology Program: Project Structure and Innovation Outcomes (Darby, Zucker, and Wang)	Measuring changes in patenting success of firms during and after ATP participation	Ordinary least-squares regression analysis, Chi-square tests; Tobit estimators
Developing a Framework for the Impact Assessment of Research Consortia Using Japanese and U.S. Data (Sakakibara and Branstetter)	Estimating the relationship between intensity of participation in joint ventures and patenting productivity	Estimating equations derived from a knowledge production function; Poisson regression analysis

Note: Studies by Austin and Macauley, 2000; and Fogarty, et al., 2000 draft, also used econometric/statistical methods, but they are treated under "Emerging Methods" in Chapter 8.

Testing ATP's Leveraging Effects on Advanced Technology Development

The Feldman-Kelley study[183] was introduced in Chapter 5 as an example of the survey method, but it is also included in this chapter since it illustrates use of econometric/statistical analysis to test the strength of hypothesized relationships. The study's tested hypotheses center on whether there is a difference in project characteristics and firm practices between firms that receive ATP awards and those that do not, and whether ATP funding makes a difference to firms in attracting additional resources. Feldman and Kelley employed multivariate analysis with control variables to provide a more stringent test of the validity of the hypothesized relationships suggested by survey findings.

Testing Whether ATP Winners and Non-Winners Differ in their Project Characteristics and Practices

Feldman and Kelley hypothesized that the following four attributes of an R&D strategy are indicative of an approach conducive to achieving ATP objectives: (1) participation in inter-organizational networks, (2) willingness to share information and to transfer it to other firms, (3) establishment of new collaborative partnerships in the project proposed, and (4) proposal of a project that is a departure from the rest of the firm's research portfolio. They wanted to know if a higher incidence of these attributes would be found in winning firms and projects than in those applicants that did not succeed in getting an award.

The survey asked questions to determine the strength of inter-organizational linkages, the tendency toward openness or secrecy, the creation of new partnerships, and the submission of proposals in new technical areas. Survey results were tabulated and tests of significance performed. Analysis of descriptive statistics showed that ATP award winners were more likely to have the four attributes than non-winners, with high statistical levels of significance.

The researchers then carried out multivariate regression analysis, using logistic regression, to test the strength of the four attributes they had identified as factors

[183]Feldman and Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect,* 2001.

influencing a firm's chances of winning an ATP award. They ran the model for three cases: (1) a base case with no controls for other factors, (2) a case controlling for past experience of applicants with ATP and with the technology area proposed, and (3) a case that adds to the controls of the second case the additional control of ATP reviewer assessment scores as proxies for the overall quality of the proposal and firm.

The multivariate regression analysis produced robust support for the hypothesis that award winners tend to be especially strong in the four attributes, and, hence, particularly well positioned to deliver public benefits from research projects that are more likely to involve new research areas and new partners than non-winners. Other findings of the regression analysis provided evidence that a firm's chance of winning an ATP award is not significantly improved by: (1) having applied to ATP in the past, (2) having been successful in past applications, or (3) spending more than non-winners on proposal preparation.

Testing Whether ATP Funding Makes a Difference

Concluding that winners differed significantly from non-winners in characteristics desirable for ATP, the researchers next presented survey findings dealing with the difference made by ATP funding. They focused on two questions: (1) how often do non-winners proceed with the proposed project as planned, and (2) compared to award winners, how successful are non-winners in attracting other sources of funding for the projects that were proposed to ATP? The tabulated survey results revealed that most non-winners did not proceed with any aspect of the proposed project or did so on a smaller scale. The survey results also indicated that fewer award winners than non-winners pursued other funding sources for their projects in the year following the ATP competition, but those who did were more than twice as likely as non-winners to attract funding.

Additional survey questions concerned winners' and non-winners' perception of the fairness of the selection process (most in both categories thought ATP's selection process was fair), their future plans to apply to ATP (the majority said they "definitely or very likely" would reapply), and whether non-winners participating in a debriefing with ATP found it helpful (most found it "very helpful" or "reasonably helpful").

From the survey findings, Feldman and Kelley hypothesized that the ATP award conveys a "halo effect" to award winners that helps them attract additional funds to their R&D project. But a halo effect is not directly observable, and the researchers used econometric/statistical analysis to test its existence. They specified a multivariate regression model that controls for other factors that may influence the firm's effectiveness in attracting additional funding from external sources. These factors included a history of success in R&D fundraising; small firm size that is associated with a dependency on external funding sources together with the availability of funding sources targeting small firms; and organizational stability that decreases business risk and thereby increases the willingness of external sources to provide funding.

The researchers estimated three regression models to investigate whether or not a halo effect exists and, if so, the strength of the effect. Model 1 controlled for: (1) whether the firm is a small business, eligible for funding from the Small Business Innovation Research and other programs targeting small entrepreneurial firms; (2) the age of the firm as a proxy for the risk of business failure; (3) the amount of external funding the firm received from non-ATP sources two years prior to ATP application as an indicator of the success of its fundraising history; and (4) the maximum scores given the proposal by ATP reviewers, as a proxy for quality differences. Model 2 included the four controls of model 1, plus a variable that distinguishes ATP award winners from their non-winning counterparts. Model 3 built on model 2 to add a set of variables reflecting major technical areas proposed to control for the popularity of technology, and, hence, their possibly greater appeal to potential funding sources. The researchers used the Tobit technique[184] to provide unbiased estimates of the relationships.

[184]In order to deal with a research question where the dependent variable of the structural estimating model is not directly observed—as is the situation in the case of the purported halo effect—standard econometric estimators are not suitable, and special estimators are needed. These include the Tobit and Probit estimators, as well as others. Econometric computational software is available for applying multivariate analysis, including logistic regression and the Tobit and Probit estimators. For additional explanation of the Tobit and Probit estimators, and software for their application, see the *TSP User's Guide,* which is publicly available for viewing and downloading at the website of the University of California, Berkeley's Econometrics Laboratory, the Software Archive (see http://elsa.berkeley.edu).

Feldman and Kelley concluded from the results of the three regression models that small firms attract more funding from non-ATP sources than other firms. They concluded that the firms' track record in fundraising is positively related to their ability to attract more funds. They found that the age of the firm matters as a predictor of a firm's ability to raise funds only when they also control for the technology area. They found that the ATP reviewer scores do not explain future fundraising success of the firms from non-ATP sources. Controlling for these other factors, they confirmed their hypothesis that winning an ATP award conveys a halo effect, allowing winners to further leverage ATP funding. In their words:[185]

> All else being equal, ATP award winners are more successful in raising funds for their projects from non-ATP sources than firms in our comparison group. These results support our thesis that the NIST/ATP selection process produces valuable information about R&D project quality and provides an information signal that other agents find credible and are willing to act upon. Furthermore, the ATP selection signal has information content beyond that provided by technical and business reviewer ratings. Through their investment decisions, other funders, private and public, are showing, by their actions, that they believe the ATP award provides additional information about the quality of the project. (p. 39)

Modeling Impacts of Public-Private Partnerships on Firm Productivity

It was noted in Chapter 4, in the initial discussion of the Griliches-Regev-Trajtenberg study[186] of the impact of government supported R&D on output, that prior studies had produced somewhat negative or contradictory findings. The researchers attempted a fresh approach to this question that is important to understanding ATP's overall effect. Because of ATP data limitations, they demonstrated their approach using comparative data from Israel.

---

185 Ibid.

186 Griliches et al., *R&D Policy in Israel: Overview and Lessons for the ATP, 2000.* (See Chapter 4 for previous discussions of this work and Chapter 9 for discussions related to the study's findings.)

Griliches-Regev-Trajtenberg Model

Griliches, Regev, and Trajtenberg identified two research perspectives for approaching the question of what difference is made by government R&D funding: (1) "looking at the firms' own R&D expenditures and asking what happened to them as a result of the availability of governmental support" and (2) looking "for differential productivity effects between own and government-supported R&D."[187] The researchers noted that the first perspective "assumes that only total R&D matters and that privately financed and government-supported R&D are perfect substitutes."[188] They noted that their inquiry along these lines "found that one dollar of government subsidy for R&D expands the firm's own R&D by $0.83 and that the difference relative to 1 is not statistically significant.[189] In contrast, the second perspective "denies that the source of funding does not matter and looks for differences in the effectiveness with which such funds are used by firms."[190] As the authors noted:

> Governmentally supported R&D may be used less efficiently if it is subject to various constraints or if entrepreneurs do not treat grants as 'their' money. It could, on the other hand, yield a higher rate of return if both the application and the selection processes choose the more promising projects, i.e., if the agencies can actually "pick winners. " (p. 8)

Applying the second research perspective, Griliches, Regev, and Trajtenberg employed the concept of effective R&D capital, where certain R&D expenditures may create more or less capital than is indicated by the amount of funding. The effect of government support of R&D on a firm's output is thus seen as a function of the extent to which this R&D enhances output (i.e., is effective). They specified effective R&D capital as follows:

$$R_e = R_o + (1 + \delta)R_g = R_T (1 + \delta s) \qquad (1)$$

where R_o and R_g are own and government-granted R&D capital, respectively; δ is the effective premium or discount on supported R&D; $R_o + R_g = R_T$ is the

187Ibid., p. 9.

188Ibid., p. 8.

189Ibid, p. 8, footnote 3.

190Ibid., p. 8.

total reported R&D; and $s = R_g/R_T$ is the share of R&D grants in total R&D expenditures. If effective R&D enters the production function logarithmically, then they rewrite its logarithm approximately as: $\log R_e = \log R_T (1 + \delta s) = \sim \log R_T + \delta s$, provided the last term is sufficiently small.[191]

They expressed a Cobb-Douglas production function, in which R&D capital services are entered as an input, as follows:

$$\log y = \Sigma \chi_k \beta_k + \gamma \log R_T + \gamma \log (1 + \delta s) \qquad (2)$$

where γ expresses the effectiveness (elasticity) of total R&D.[192]

Demonstrating the Model with Israeli Data

Data to estimate this equation were drawn from what is described as a unique panel set of firm-level data generated by surveys performed by Israel's Central Bureau of Statistics and the Ministry of Industry and Trade. The dataset "brings together statistics from various sources."[193] The use of a panel was seen as "especially appropriate in a study on the implications of R&D support for a firm's performance, because it reveals correspondences between productivity at different points in time and R&D investments, activity, and funding type in previous periods."[194] The use of a panel also permitted construction of a set of comparison groups, including those firms that conducted R&D and which reported receiving government grants, firms that conducted R&D but which did not receive grants, and firms that did not report any formal R&D activity. The study's findings, based on data from Israeli programs similar to ATP, suggested that the impact on firm productivity of government support to private firm R&D is positive.

Spillovers, Appropriability, and Firm Productivity

Spillovers play a central role in justifying public support for R&D, yet they are difficult to identify and measure. Improving the methods of quantifying spillovers is an important goal for a public R&D program like ATP.

[191]Ibid., p. 8.
[192]Ibid., p. 10.
[193]Ibid., p. 10.
[194]Ibid., p. 11.

In their study, Wesley Cohen, Carnegie Mellon University, and John Walsh, University of Illinois-Chicago,[195] linked consideration of spillovers to that of appropriability. That is, they linked the degree to which firms are able to protect the profitability of their own inventions and the strategies they use to achieve appropriability.

Cohen and Walsh attempted to control for the negative relationships between R&D appropriability and R&D knowledge flows, thus isolating the knowledge spillover effects of R&D on the productivity of R&D at the industry level. Their objective was germane to ATP's core mission of increasing the returns to industry-level R&D and technological innovation (as opposed to producing benefits appropriable only by a single firm) and to ATP's program emphasis on joint ventures.

Cohen and Walsh defined appropriability as "the degree to which different appropriability mechanisms, such as secrecy, patents, or the exploitation of first mover advantages, increase the rents[196] due to R&D...."[197] Flows of R&D-related information, in their study, have two offsetting effects on a firm's interest in investing in R&D. On the one hand, information flow diminishes appropriability, and thus dampens incentives to conduct R&D. On the other hand, it increases the R&D productivity of the firms that receive spillover flows, and in turn increases the productivity of R&D conducted at the industry level.

The diagram in Figure 7–1 illustrates the hypothesized relationships. In the researchers' words:

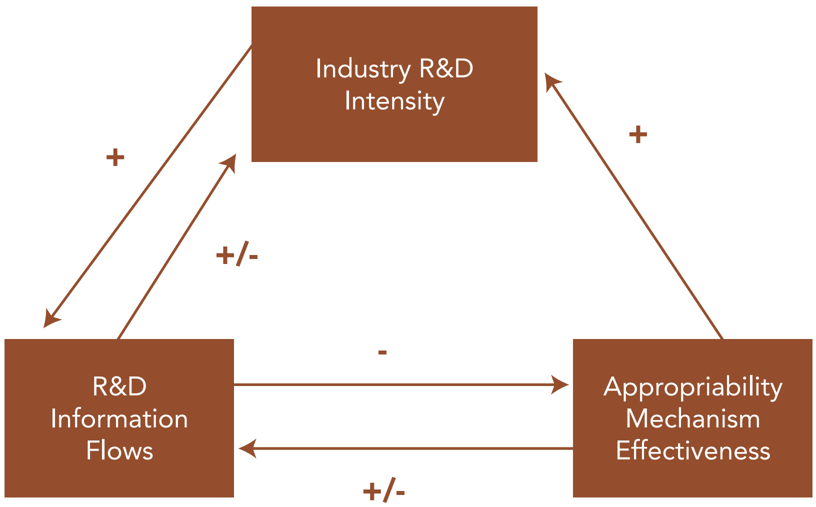
> To the degree that R&D related information flows are stronger within an industry, the more difficult appropriation of rents to R&D will be, notwithstanding the particular appropriability mechanism employed. However, use of different appropriability mechanisms may, at the same time, diminish the extent and value to rivals of intra-industry information flows. For example, to the degree that secrecy is used and is effective, we would expect information flows to be less than if patents are used since patents, while offering protection, also disclose information. (p. 9)

195Wesley M. Cohen and John P. Walsh, *R&D Spillovers, Appropriability and R&D Intensity: A Survey Based Approach,* Draft report, ATP, 2000.

196Rent in this case refers to a return in excess of a competitive rate of return.

197Ibid., p. 9

Figure 7–1. Relationships across Industry R&D Intensity, Intra-Industry R&D Information Flows, and Appropriability Mechanism Effectiveness



Source: Cohen and Walsh, *R&D Spillovers, Appropriability and R&D Intensity: A Survey Based Approach,* 2000, p. 44.

Cohen-Walsh Method of Isolating Knowledge Spillover Effects on Productivity

In their study, Cohen and Walsh constructed a simultaneous equation model that expressly links the dependent variables—R&D intensity, appropriability, and information flows—to firm and industry level economic variables. They identified "R&D intensity" as the sales-weighted average of the R&D intensities of business units in each industry.

Their measure of appropriability was based on the responses of firms to six appropriability mechanisms, including secrecy and patents. Their measure of information flows, which was also taken from survey data, reflected the percentage of respondents in an industry reporting that information from rivals suggested new R&D projects.

Given their specification of five dependent variables, Cohen and Walsh specified a set of five simultaneous equations to determine them. One equation expressed R&D intensity as a function of appropriability and intra-industry R&D information flows, controlling for market-mediated information flows, information from suppliers, generic science base, and demand growth. The second equation expressed information flows as a function of industry R&D intensity and appropriability, controlling for market-mediated information flows, number of technological competitors, and extra industry information from suppliers, customers, and universities. The third, fourth, and fifth equations expressed three aspects of the appropriability mechanism. The researchers used two- and three-stage least squares estimation techniques to solve the equations.

Testing the Model with Data from the 1994 Carnegie Mellon Survey on Industrial R&D

The researchers tested the model with data from an extensive, existing database constructed from a 1994 survey of industrial R&D in the United States. Referred to as the Carnegie Mellon Survey, the mail survey was sent to R&D unit directors for manufacturing firms.[198] A distinguishing feature of the data from this survey is that it provides separate measures of appropriability and intra-industry R&D information flows, thus permitting "control for the effect of intra-industry R&D information flows on appropriability," thus, in turn, making it possible to "observe the possibly countervailing effect of these flows on R&D itself."[199] Cohen and Walsh obtained other firm- and industry-level data for their study from standard sources (e.g., COMPUSTAT and Census of Manufacturers' (1992) special surveys).

Study Findings

Study findings suggested that "...the direct influence of intra-industry R&D information flows is strongly complementary to R&D at the industry level..."[200]

[198]Wesley Cohen and Richard Nelson conducted the survey.

[199]Ibid., p. 5.

[200]Ibid., p. 20.

Overall, the study's key findings were that:

- The more appropriable are the rents to R&D, the higher the R&D intensity of an industry;
- There is a negative relationship between selected appropriability mechanisms (particularly secrecy) and intra-industry R&D-related information flows; and
- Intra-industry R&D-related information flows lead to greater R&D intensity.

The study findings indicated that, "…controlling for the effect of intra-industry information flows on appropriability, intraindustry R&D information flows complement firms' own R&D efforts, underscoring the social welfare benefits of such flows."[201] These findings are consistent with fundamental propositions leading to ATP's establishment. They also point to the possibilities of industry-wide as opposed to firm specific benefits from ATP awards.

The study's limitations are candidly noted, and indeed may be seen as representative of the problems and limitations encountered in econometric work. The limitations include considerable measurement error in the survey-based measures, the *ad hoc* character of some model specifications for which there is little theory to offer guidance, the opportunistic character of some model specifications driven mainly by the availability of data, and the lack of robustness of a number of findings across model specifications and estimation methods.

Analyzing the Role of Universities in Public-Private Partnerships

Bronwyn Hall, University of California, Berkeley and National Bureau of Economic Research (NBER), Albert Link, University of North Carolina-Greensboro, and John Scott, Dartmouth College, used Probit and Tobit estimators to analyze survey results to explore the role of universities as research partners in ATP-funded projects.[202] They were dealing with a research question that entails a

[201]Ibid., p.6.

[202]Hall et al., *Universities as Research Partners,* 2002.

dependent variable that, like the halo effect, is not directly observable, thereby requiring the use of the non-standard estimators.

What Role do Universities Play in Research Partnerships?

The study explored the research role universities play in ATP-funded projects at three levels. First, the researchers simply looked at the organizational role the universities had in the various projects—either as a research partner or as a subcontractor. Second, they explored the research role played by universities by asking project representatives to respond to a statement that "this research project has experienced difficulties acquiring and assimilating basic knowledge necessary for the project's progress." To examine the responses to the statement more systematically, they estimated Probit models to explain inter-project differences in responses to the statement.[203]

Hall, et al., made the following observations based on their results:

- Respondents with a university participant (as a research partner or as a subcontractor) systematically agreed that their projects experienced difficulties acquiring and assimilating basic knowledge necessary for progress toward completion.
- Prior experience working with a university as a research partner or as a subcontractor is a very significant factor in decreasing the difficulty of acquiring and assimilating basic knowledge.
- Acquisition and assimilation difficulties with basic knowledge decrease slightly as overall project size increases.
- Projects in the electronics area have substantially more difficulty in acquiring and assimilating basic knowledge than do projects in other technology areas. (p. 18.)

Do Universities Enhance the Research Efficiency of Research Partnerships?

Descriptive statistics from the survey did not provide a clear answer to the question of whether universities enhance the research efficiency of research partnerships.

[203] As explained earlier, in some circumstances standard econometric estimators are not suitable for testing hypotheses, and special estimators are needed.

The descriptive statistics were based on survey responses to a series of three statements about unexpected research problems encountered, and to a series of two statements about the productive use of complementary research resources. In the absence of a clear response pattern to the survey questions, the researchers examined the responses more systematically using Probit models. However, in this case the Probit models also did not show any significant, identifiable effects of universities on the efficiency of research partnerships. The researchers concluded that the presence of unexpected problems is either a random event or too complex to disentangle using their approach.[204]

Do Universities Affect the Development and Commercialization of Industry Technology?

To address this question, the researchers asked survey respondents to respond to two statements. One of the statements regarded the generation of new applications of the technology over the course of the project. Survey results showed conflicting results between joint ventures and single applicants. Using Probit estimates also produced insignificant results regarding university influence on the generation of new applications of technology developed in projects.

The second statement concerned faster-than-expected commercialization of the technology. Survey statistics showed single applicants with no university involvement to be the most optimistic about accelerated commercialization. The Probit estimates shed further light on the relationship between university involvement and technology commercialization. Projects involving universities as partners were found to be less likely to develop and commercialize technology sooner than expected. The researchers speculated about possible explanatory factors.[205]

Is There a Relationship Between University Involvement and Project Termination?

Hall et al., also investigated the relationship between university involvement in an ATP-funded project and the probability that the project will terminate early, using the following Probit model:

---

[204]Ibid., pp. 18–19.

[205]Ibid., pp. 22–26.

Probability that project i terminates early = $F(X_i\beta)$,

where F is the cumulative normal probability function, and X_i is a vector of variables that characterizes project *i*. The variables are ATP's share of funding, involvement of a university, type of project, size of the lead participant, technology area, and a time variable denoting the year in which each project was initially funded.

The model was applied to the analysis of 21 projects that had terminated prior to completion. The group of terminated projects included 11 joint ventures, three of which included a university as a research partner and two others that included a university as a subcontractor, and 10 single companies, 4 of which included a university as a subcontractor. Hence, of the 21 projects in the group 9 involved a university and 12 did not.

Hall et al., calculated Probit estimates using alternative specifications of the above equation. Using the results of the Probit analysis to control for possible sample selection bias, they concluded that the calculated probability of early termination is lower for each discrete level of ATP's share of funding when a university is involved in the project.[206]

Modeling the Impact of Publishing by Industry Scientists on the Quality of Innovative Output

Bruce Kogut, University of Pennsylvania's Wharton School, and Michelle Gittelman, New York University's Stern School of Business, carried out an econometric/statistical study to help clarify the relationship between publishing by a firm's scientists and the firm's innovative output as indicated by citations of its patents.[207] Their approach was based on a growing body of empirical research provided by Trajtenberg, Harhoff, Narin, Sherer, Vopel, Lerner, Shane, and others. That body of research indicates that "patent citations contain information about a patent's technological importance, and that they can also be used as a

[206]Ibid., pp. 11–13.

[207]Bruce Kogut and Michelle Gittelman, *Public-Private Partnering and Innovation Performance Among U.S. Biotechnology Firms,* Draft report, ATP, 2001.

proxy for economic value."[208] The study is relevant to ATP in that it bears on the appropriability of returns of publicly funded research, and on the importance of collaborations to realize the benefits of research in commercial applications.

Exploring Two Questions about the Relationship of Publishing and Patenting

The study examined firm experience in the biotechnology area of human therapeutics, an important area for ATP project funding. Kogut and Gittelman selected the biotechnology area as an industry in which "the productivity of a firm's R&D investments can be greatly improved by incorporating scientific research into the firm... a process that involves the transformation of codifiable knowledge into tangible goods, services and technologies."[209] Figure 7–2 illustrates how, in the emerging field of gene therapy, acceleration of the rate of publishing seems to lead to acceleration of the rate of patenting.

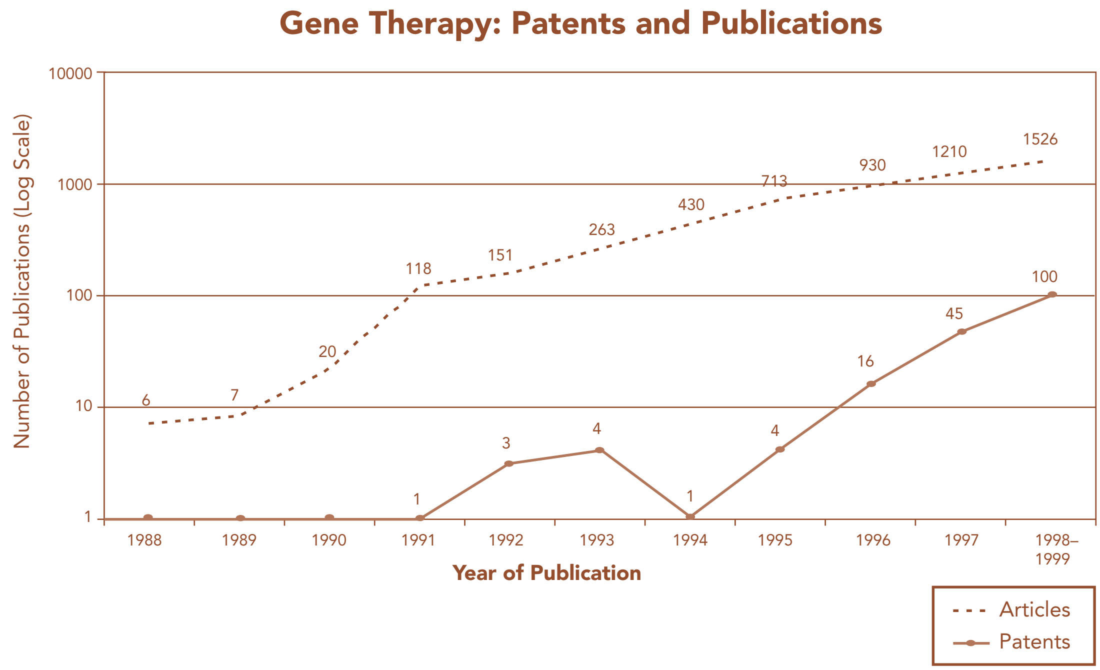
Kogut and Gittelman focused on answering two questions: (1) Do investments in scientific research, as proxied by publications, pay off for the firm in terms of producing valuable firm-level research capabilities, as proxied by patents? (2) Does the firm's research capabilities and collaborations, as proxied by co-publications, affect the quality of commercial innovation, as measured by patent citations? (Their measure of the quality of innovative output was based on the number of citations of the firm's patents by other firms in subsequent patents.)

Kogut and Gittelman had a special interest in the effect of industry-based scientists co-publishing with university-based scientists, noting that, "Direct linkages between firms and universities are likely to be an important organizational arrangement by which research-oriented firms extract gains from the complementarities between scientific research and technological innovation."[210] When ATP-funded projects include university participation, opportunities for co-publishing between firm scientists and university scientists are increased. Understanding the implications of stimulating this form of collaboration is relevant to ATP project selection.

---

[208]Ibid., p. 26.
[209]Ibid., p. 2.
[210]Ibid., p. 2.

Figure 7–2. Patenting and Publishing in the Scientific Literature, Gene Therapy: Patents and Publications



Source: Kogut and Gittelman, *Public-Private Partnering and Innovation Performance Among U.S. Biotechnology Firms,* 2001, p. 4.

Approach to Addressing the Questions

The general approach used by Kogut and Gittelman was to develop models of patenting and publication, develop a sampling strategy, compile data, and apply the models to address the two questions.

Because of several sampling problems, Kogut and Gittelman decided against selecting the data sample primarily from ATP firms. First of all, many of the

ATP biotechnology patents were too recent to support use of citation analysis as a performance measure. Second, insufficient time had passed to build evidence of co-publishing/partnering relationships. And finally, Kogut and Gittelman felt that patenting in ATP-funded biotechnology projects was not representative of the importance of patenting as a means of protecting assets in other areas of biotechnology.[211]

For these reasons, Kogut and Gittelman drew an initial sample of firms from U.S. biotechnology firms at large. This sample included 114 firms, of which seven of the companies were participants in ATP-funded projects. They then added 39 companies with ATP-funded projects, for a total of 153 companies in the sample.

Kogut and Gittelman collected four sets of data for the sample firms: data on publications in scientific literature, patent data, scientist data, and data for firm-level characteristics.[212] They identified 20,477 publications by authors in the sample; and 2,269 patenting authors, of which 35% were also listed on a publication.[213]

Kogut and Gittelman developed several predictive models, the dependent variable of which was the cumulative forward citation frequencies to all patents in a patent family. The explanatory variables include firm effects, scientist effects, firm-level controls, and patent-level controls.

Applying negative binomial regression as their estimation technique, Kogut and Gittelman obtained firm and patent-level measures from four models they developed. The first model included only control variables, the second model added the log of the number of publications by the firm up to the year of the observed patent, the third model included only firm-level publishing variables, and the fourth model added patent-level measures. Kogut and Gittelman used the models separately to measure firm effects and patent-level effects.

[211]Ibid., p. 8.
[212]Ibid., p. 9.
[213]Ibid., pp. 12–13.

Kogut-Gittelman Findings

Kogut and Gittelman concluded, "Research capabilities and the innovative capabilities of biotechnology are linked through complex, indirect pathways."[214] Specific findings from the study were as follows:[215]

- Research-intensive firms contribute new knowledge to the public domain through scientific publications.
- Collaboration with universities is a central mechanism by which biotechnology firms acquire knowledge and disseminate research findings.
- Larger firms account for the greatest volume of scientific outputs.
- Younger and smaller firms tend to publish at the forefront of discovery.
- Younger and smaller firms produce the most highly cited articles.
- Collaboration plays different roles for firms with different research capabilities.
- Firms that lack strong in-house research capabilities improve their research performance by collaborating; firms with strong research capabilities collaborate just as much as weak ones, but collaboration does not improve their research performance.
- The more a patent builds on scientific literature, the more it is cited.
- Good patents build on science, but firms that publish a lot of good quality science do worse in producing highly cited patents.
- Investment in firm-level scientific research may be necessary to allow the firm to translate scientific findings into innovative projects, but the actual outputs of that research—contributions to the scientific literature—do not appear to pay off directly on the commercial side.

Kogut and Gittelman's findings have implications for ATP in that they reinforce the argument that firms find it difficult to appropriate the returns to scientific research placed in the public domain. Though firms nevertheless gain from performing research, they need to do more than publish; they need

[214]Ibid., p. 35.
[215]Ibid., pp. 33–35.

direct connections with those who translate knowledge into commercial applications. "Public-private partnering is a key organizational arrangement by which this process occurs," according to the authors.[216]

Investigating Characteristics and Impacts of Joint Ventures

ATP has funded several econometric/statistical studies to assess the impact of joint ventures and the characteristics of the partners to the joint ventures. These studies encompass many of the issues of data selection and collection, model specification, and interpretation that are typical of econometric studies.

The logic of private sector joint ventures, in large part, relates to the sharing of R&D costs, the spreading of risks, the exploitation of scale economies in R&D, the access to new capabilities among several firms, and supply-chain linkages to accelerate technology development and commercialization. For the public sector to support these joint ventures, the logic expands to include the generation and utilization of spillovers,[217] and the fostering of joint venture formations.

As noted by David Mowery, University of California, Berkeley, Joanne Oxley, University of Michigan, and Brian Silverman, University of Toronto, in their report, "Economists have long argued that consortia have the potential to internalize spillovers of technological knowledge among firms, thereby reducing disincentives to invest in R&D and encouraging more rapid diffusion of technology among firms."[218] They also note that the effects of consortia on the incidence of spillovers "have received very little empirical attention," and further, "[a] better empirical framework for such analyses is essential to effective evaluation."[219]

[216]Ibid., p. 35.

[217]"Among the hypothesized benefits of consortia, knowledge spillovers provide the strongest motivation for public investment in their formation and operation," according to David C. Mowery, Joanne E. Oxley, and Brian S. Silverman, *The Role of Knowledge Spillovers in ATP Consortia,* Draft report, ATP, 1998, p. 2.

[218]Ibid., p. i.

[219]Ibid., p. i.

Study of Spillovers and Consortia

The Mowery et al., study addressed several aspects of the relationship between spillovers and consortia (or joint ventures).[220] In particular, the study investigated the influence of inter-firm knowledge spillovers on ATP's selection of awardees, and the extent to which an ATP award affects the level of spillovers among members of a joint venture. In each case, a set of prior theoretical propositions was used to formulate a specific testable hypothesis.

Three Hypotheses

The study set forth the following three hypotheses:

> H1: If ATP-supported consortia favor the internalization of knowledge spillovers among member firms, the probability that ATP will fund a consortium proposal should increase as the level of patent cross-citation among this group of firms increases.
>
> H2: Firms participating in a consortium will cite one another's patents more heavily following the formation of the consortium.
>
> H3: Firms participating in a consortium will tend to cite one another's patents more rapidly after the issuance of these patents than was true prior to the formation of the consortium. (p. 6)

Mowery et al., noted that knowledge spillover benefits should apply equally to horizontal and vertical consortia, and, in fact, most consortia involve both horizontal and vertical elements. They also acknowledged that the conceptual framework underpinning H1 "…ignores other possible influences on the formation of consortia."[221]

They pointed to theoretical propositions suggesting "...consortia are likely to be more effective when they involve as members firms that generate a high level of

[220] For the purpose of this discussion, the terms "consortia" and "joint venture" are used interchangeably.

[221] Ibid., p. 13.

spillovers among themselves in the absence of a consortium."[222] The second and third hypotheses related to the post-formation behavior of a consortium in terms of its effectiveness in generating knowledge spillovers. The crafting of these hypotheses is of interest because the hypotheses detailed important aspects of evaluation design, including selection of the proxy variable, specification of a control group, and the role of trend and history as confounding explanations.

Patent Citations as a Measure of Spillovers

The measure of R&D spillovers used in this study—as in several other studies supported by ATP—is the citation of other firms' patents in a firm's own patent applications. Like the other researchers who have used this measure, Mowery et al., explicitly noted that patents are not a perfect measure of innovative output. Patents relate only to codified knowledge relevant to a new invention or technology. In addition, there are significant inter-firm differences in patenting behavior. Still, they noted that patents have certain advantages in empirical work: "All patents include a section devoted to citations of related patents, and these citations can be interpreted as a measure of inter-firm spillovers of knowledge."[223] Also, patents are accessible in machine-readable form, which reduces the cost and increases the flexibility of using these data.

Constructing Portfolios of Patent Data for Testing the Hypotheses

To bound the empirical work, Mowery et al., compiled patent-related data for four groups of consortia: (1) semiconductor-related patent data compiled from members of the SEMATECH Research Corporation for patents mainly derived from SEMATECH research (SEMATECH, a consortium founded in 1987, provides a longer history than ATP); (2) control groups of patent data from SEMATECH members not derived from SEMATECH research, from U.S. firms that are not members of SEMATECH, and from U.S. universities and federal laboratories (the SEMATECH and control group data were compiled for the 1985–1995 period); (3) patent data compiled for participants in ATP-funded joint

[222]Ibid., p. 2.

[223]Ibid., p. 5.

ventures; and (4) patent data compiled for unsuccessful joint venture applicants to ATP. The researchers also compiled a "complete dataset on the ownership of all firms in the sample, in order to minimize spurious results from the analysis of patent cross-citations among these firms..."[224]

Study Design

The study design called for a before-and-after SEMATECH analysis, a before-and-after ATP analysis, and a comparison of the patenting experience of SEMATECH member firms with the before-and-after experience of consortia that did not receive federal funding. The research team, however, stated that it was not able to construct a control sample of consortia for which it was certain no public subsidies had been received, and thus did not conduct the latter comparison.

The purpose of the SEMATECH analysis was to test the analytical approach proposed for H2 and H3 for ATP joint ventures, and to provide additional insights about the hypothesized relationships. The researchers believed SEMATECH's longer patenting history offered a better proving ground for the approach than would ATP.

With respect to the testing of H1, which pertained to the influence of pre-application cross-citations on ATP's selection of a joint venture for funding, the underlying model was as follows: The dependent variable, SUCCESS (which was given a value of 1 for successful applications to ATP and 0 for unsuccessful applications), was treated as a function of patent cross-citations, PCROSS, which was defined as follows:

$$\text{PCROSS} = \Sigma\ [\ (\text{citation}_{i,\ j \neq i}/\text{total cites}_i)]/N$$

where firm i = the citing firm, firm j = the cited firms in the same group, and N = the total number of firms in the group.

As the researchers acknowledged, they lacked a full set of controls for potential influences on ATP funding decisions. However, they did control for a number of factors, including: the number of firms in a given application to ATP, the level of

[224]Ibid., p. i.

experience collaborating, whether the application was to an ATP focused program competition or a general competition, and the average number of patents per firm in the application.[225]

With respect to H2 and H3, which pertained to the extent and speed of inter-firm cross-citations following establishment of the consortia, the researchers focused on SEMATECH. They used a modified approach to test H1 for SEMATECH to reflect the fact that they were working with only one consortium. For 10 SEMATECH firms, they matched each SEMATECH member firm with a non-member firm from the control group, acknowledging that the control group firms were imperfect matches. The researchers compared the number of relevant patents assigned to each from 1975–96, and the number of citations of these patents. They tested a modified version of H1 for SEMATECH.

Mowery et al., Findings

The researchers concluded that the preliminary results of their testing of the hypotheses using SEMATECH data "are not especially encouraging." With respect to H1, they concluded:[226]

> ...although SEMATECH firms display relatively high levels of knowledge spillovers among themselves prior to the formation of the consortium, we find no evidence that these spillovers have increased since SEMATECH's establishment, nor do we find that member firms have been able to exploit one another's patents more rapidly since the establishment of the consortium. (pp. 26–27)

In testing H1as it applied to ATP, the researchers concluded:[226]

> Although they omit some important influences on ATP selection outcomes, these results suggest either that patent cross-citations only weakly proxy the "true" inter-firm knowledge spillovers that may influence the outcome of ATP consortium funding competitions, or

225Ibid., pp. 8–9.

226The researchers concluded that it was premature to test H2 and H3 using ATP data.

> that such pre-consortium spillovers exert a relatively weak influence on ATP's awards. (p. 13)

In view of this finding suggesting little evidence that ATP funds are deliberately directed toward internalizing spillovers among firms with substantial pre-ATP spillovers, the researchers debated the desirability of this policy orientation. They concluded that, indeed, it might be desirable, based on related prior findings suggesting that firms with high levels of cross-citations might not require public subsidies to encourage them to form consortia. In the words of the researchers:

> In this view, publicly funded consortia should involve firms that exhibit a level of pre-consortium knowledge spillovers that is lower than the level of spillovers observed among firms that form unsubsidized alliances or consortia. (p. 14)

The researchers pointed out that, on the other hand, consortium performance is probably improved by some degree of "technological overlap" that helps mutual understanding and absorption of research results. Mowery et al. concluded that a larger sample of collaborative ventures is needed to improve the strength of their results.

Darby et al., Study of Joint Venture Effects on Participating Firms

Michael Darby and Lynne Zucker, University of California, Los Angeles and the National Bureau of Economic Research and Andrew Wang of ATP also used econometric/statistical techniques to study the effects on firms participating in ATP-funded joint ventures.[227] The Darby et al., study focused on comparisons between single firm and joint venture projects. For each type of project, the researchers investigated the role of university participation either as a full member in a joint venture or as a subcontractor for a single firm or joint venture project. The basic hypotheses of the study were that participation in a joint venture should increase the patenting rate of participating firms, and that the effect should be larger if the firm has a university partner or university subcontractor.

[227] Michael R. Darby, Lynne G. Zucker, and Andrew Wang, *Program Design and Firm Success in the Advanced Technology Program: Project Structure and Innovation Outcomes,* NISTIR 6943 (Gaithersburg, MD: National Institute of Standards and Technology, 2002).

Study Design

The study design entailed a before-and-after comparison of innovation outcomes, using the firm/organization as the unit of analysis and patent data as the key indicator of impact on firm innovation. In fact, the researchers stated, "Patents, in representing an active business decision to protect commercially valuable inventions, are arguably the single best proxy measure of innovation."[228] They tracked patenting by ATP awardees before, during and after they became ATP participants. A hierarchy of settings also was constructed, indicating whether a firm was a full partner in a joint venture or a single firm participant, and, given this initial classification, whether or not it had a university as a collaborator or a subcontractor. The time period covered by the patent series was 1988–1996.

The authors developed a "deflated" patent count measure for their dataset, which is adjusted for year-to-year changes in the average rate of patenting as measured by patents per assignee for all U.S. assignees of U.S. patents. This adjustment was necessary to reflect national trends in the rate of patent applications and the speed with which patents were processed. ("A simple before-and-after comparison of patenting is therefore subject to the criticism that it reflects trend increases in patenting rather than identifying real program impact.")[229]

Darby, et al. Findings

In a cross-section before-and-after comparison of each firm that participated in ATP projects that started by the end of 1995, the authors controlled for firm size, industry, total amount of ATP funds received, and year of participation. Results from a series of regressions based on these controls indicated that both single firm and joint venture participants increase their patenting when they have university partners or university subcontractors.

Although the magnitude of the impact varied across model specifications, the authors concluded, that before-and-after patenting rates generally increase after ATP participation under a number of different program and participant

[228] Ibid., p. 6.
[229] Ibid., p. 10.

variations. "For firms in the sample, patenting increased on average by between 5 and 30 patents per year during the period of participation. These estimates are conservative since future effects from the ATP project participation are not included, even though they are implied in [the] regression models."[230] The estimated impact on patenting rates was higher for firms that participated in joint ventures than for single firms, and for both sets of those firms that had university partners.

Changing the "Social Embeddedness" of Firms

The Darby et al., study offers additional *a priori* justification for the emphasis of ATP's program design on joint ventures and the participation of universities as R&D performers. The researchers credit the ATP awards with changing the "social embeddedness" of participants in networks of relationships with other firms and other organizations. ATP is thus seen not only as providing awards to participants but also "fostering institutions and social processes that facilitate innovation."[231]

Sakakibara-Branstetter Impact Study of Joint Ventures

The Mowery et al., and Darby et al., studies examined the effects of firm participation in joint ventures in a before-and-after mode of evaluation. Mariko Sakakibara, UCLA, and Lee Branstetter, Columbia Business School, also used an econometric/statistical approach to modeling the effects of firm participation in joint ventures, but took a different angle from these other studies.[232]

Sakakibara and Branstetter examined the impact of ATP-funded consortia on the *ex post* research productivity of participating firms. Their thesis was that if participation in an ATP-sponsored consortium increased the research productivity of member firms by "promoting research spillovers among members," and allowing for exchange of complementary knowledge assets, then there should

[230]Ibid., p. 19

[231]Ibid., p. 20.

[232]Sakakibara and Branstetter, *Measuring the Impact of ATP-Funded Research Consortia on Research Productivity of Participating Firms: A Framework Using Both U.S. and Japanese Data,* 2002.

be a statistical relationship between the number of ATP consortia a firm is involved in during a given year, and the firm's patent output in that year.[233] The authors noted that a lag structure should be introduced, but cited the limited time-series dimension of their U.S. data as a reason for not building lags into several of their estimation equations. They tested their hypothesis using panel data on participating firms and a control group of non-participants.

Three Research Questions

The study was subdivided into three research questions of growing econometric complexity: (1) To what extent does participation in an ATP research consortium contribute to an overall expansion of research productivity among participating firms? (2) What impact does participation in research consortium have on the collective patenting of participating firms in the technological areas targeted by the consortia—within which is nested the further question of what kinds of consortia are the most successful at promoting the *ex post* research productivity of participating firms? (3) How are benefits from participation in an ATP-financed consortium distributed by type of firm?

Testing the Model with Japanese Data

As explained in Chapter 4, the study used data from publicly funded Japanese research consortia as a "statistical 'testing ground' for the analytical frameworks that were applied to U.S. data…"[234] An important aspect of this framework was that it highlights the importance of the length of time covered by the data series. Japanese public sector support of R&D consortia dates back to the 1950s, and Sakakibara and Branstetter reported construction of a dataset for Japan that goes back to the early 1980s. ATP projects were begun in 1990–1991, with only a small number of projects funded until the mid-1990s. However, public databases on patent information and R&D spending available to the researchers only extend to 1995 just as ATP was expanding its support of research consortia.[235] This difference in length of data series is important, according to the researchers, because:

[233]Ibid., p. 6.
[234]Ibid., p. xiii.
[235]Ibid., pp. xiv-xv.

> ...results from Japanese data suggest that much of the impact of research consortia is felt long after the inception of the project. In fact, evidence from the Japanese consortia suggests that some of the strongest effects are felt *after the official cessation of the consortia.* (p. xiv, emphasis in the original)

Applying the Model to ATP Data

Sakakibara and Branstetter drew from their previous work[236] to construct a model to determine if there is an observable statistical relationship between the intensity of participation in an ATP-funded joint venture by a firm and the firm's patent output in that year. They acknowledged that the role of lags is of interest in addressing this question, but they stated that the "limited time-series dimension of our data does not allow us to adequately explore this question, but we do introduce a lag structure in subsequent empirical sections." They used the following log-linear equation to address the question:

$$\rho_{it} = ß_0 + ß_1 r_{it} + ß_2 C_{it} + \sum_d \delta_d D_{id} + \mu_{it}$$

where ρ_{it} = natural log of the number of patents generated by firm i in year t; r_{it} = the natural log of firm-level R&D spending; C_{it} = the intensity of participation in research consortia, measured as the count of concurrent projects in which firm i was involved in year t; δ's = the coefficients on the industry dummy variables (Ds); μ = an error term; and δ terms are industry-level differences in the propensity to patent.[237]

U.S. data used in the estimation equation consisted of panel data for 249 firms, 65 of which had participated in at least one ATP project; the data covered the years 1985–1995. The panel was unbalanced in that participant firms tended to be larger, conducted more R&D, and generated more patents than the non-participant sample.[238]

7. Econometric/Statistical Method

---

[236]Lee Branstetter and Mariko Sakakibara, "Japanese Research Consortia: A Microeconometric Analysis of Industrial Policy," *Journal of Industrial Economics,* 46: 207–233,1998.

[237]Sakakibara and Branstetter, *Measuring the Impact of ATP-Funded Research Consortia on Research Productivity of Participating Firms: A Framework Using Both U.S. and Japanese Data,* 2002, p. 5.

[238]Ibid., pp. 7–8.

Sakakibara-Branstetter Findings

The study found that "Controlling for firm size, impact of participation in ATP-funded consortia on research output remains positive and significant in all specifications."[239] In quantitative terms, the researchers concluded, "participation in one additional ATP-funded research consortium per year would generate an increase in patenting in that year of nearly 8%."[240] They also cited evidence that "large firms conducting intensive research and development (R&D) tend to benefit more from their participation in consortia"[241] but prudently cautioned against jumping to conclusions based on these results because of the several difficulties the study encountered in constructing a reasonably lengthy time series of data and a representative comparison group.

A major limitation of the study, as noted above, was the truncation of the time series dimension of the U.S. data. Thus, the researchers believed it is likely that a large share, perhaps the largest share, of the benefits from participation in ATP was missing from the data available at the time they performed the study. Difficulties were also encountered in obtaining data on the smaller firms that are involved in ATP-sponsored consortia. In their words:

> While it is relatively easy to obtain data on the larger, publicly traded firms that were part of these projects, it is difficult to obtain similar data on small, privately held firms that were often leaders of the joint ventures. Lack of data on smaller firms limits our ability to estimate the impact of ATP-funded consortia on their research productivity. If smaller firms benefit more from consortia participation than do larger firms, then our data may underestimate the impact of ATP-funded consortia on smaller firms. (p. xv)

Sakakibara and Branstetter found that ATP's confidentiality agreement constrained their access to data. They noted that participating firms submitted a substantial amount of information to ATP through the Business Reporting System (BRS) (see Chapter 5.) Because the information submitted through BRS is divulged under an

[239]Ibid., p. 13.
[240]Ibid., p. 13.
[241]Ibid., vi.

agreement between the firms and ATP to maintain the confidentiality of the information, they were not able to examine firm's individual responses to survey questions about the impacts of various projects.[242]

Emphasis on Data

The attention to data compilation and quality is a singular feature of the Sakakibara-Branstetter study. Indeed, in noting that they have provided ATP with full documentation of the database used in the study, the authors expressed their hope that "these tables and documentation will be a useful, enduring data resource for ATP." (p. xviii)

Summary of Econometric/Statistical Methods

By the end of ATP's first decade, use of the econometric/statistical method constituted an increasingly important component of ATP's evaluation program. While many of the studies were exploratory in nature, use of econometric/statistics methods contributed to ATP's ability to test hypotheses about underlying relationships and answer demanding questions about the program's net contribution, and what might have happened in the absence of the program. By embedding procedures such as before/after comparisons and the use of control groups in research design, the methods were used to control for alternative explanations of observed behavior. They have also been used to strengthen statistical tests of the significance of effects not directly observable, such as the halo effect, and to identify characteristics associated with awarded projects. Econometric/statistical studies have also helped define and clarify key ATP program theory concepts, such as the impact of the program on firm productivity.

As noted, several of the studies surveyed in this chapter dealt with measures of spillovers, a key justification for public sector support of firm-specific R&D, but a concept not widely used outside economics. Despite their limitations, these studies have provided a methodologically more consistent, replicable, and convincing form of evidence about program impacts than the evaluation methods described in earlier chapters.

[242] Ibid., see p. xv.

The findings of the group of studies presented here are as much about the existence of positive impacts (e.g., the presence of spillovers) as they are about the absence of negatives (e.g., that ATP funding does not displace private-sector R&D funds). The findings are rich in new insights about the program. They also help confirm concepts suggested by other methods, such as the halo effect. They point to differential impacts of ATP support depending on the structure and social context of joint ventures, and depending on the presence or absence of universities as project participants or subcontractors. Obviously, information of this type can inform those charged with assessing proposals against ATP's selection criteria.

As emphasized throughout this chapter, econometric/statistical methods involve extensive efforts at creating primary datasets and the refinement of existing datasets. Thus, the studies provide a foundation for subsequent work by others in examining multiple dimensions of the program. The attention given to data collection by the studies highlights the fact that use of econometric/statistical methods, particularly at the initial phases of a program's operations, requires major up-front investments in data construction. It confirms a point made in Chapter 3: that econometrics is as much about identification, collection, and cleaning primary data as it is about model formulation and statistical techniques. The attention to data collection, in addition to model development, also reinforces the observation that ATP's evaluation program generates its own spillovers. By supporting primary data collection, ATP provides a common pool resource that can be used by others studying ATP's impacts as well as by researchers and decision makers interested in generic processes of technological innovation or of joint ventures.

The limits of the methods are also evident in this collection of studies, especially as several authors were quite candid about the *ad hoc* character of some of their model specifications, and the tentative, qualified character of their findings. Several researchers, in fact, pointed to the atheoretical formulation of their estimation equations and their findings' lack of robustness, meaning that findings about impacts were heavily dependent on the formulation of a model.

Several studies also noted problems associated with data collection. The chief problem was the short period for which public data were available (e.g., patent data), thus truncating analysis of long-term impacts. Other data problems included difficulties in constructing balanced comparison groups, limited access to confidential ATP records, and the heavy dependence of several of the studies on patent data. Although patent data are widely used in econometric studies of the impacts of R&D, they are certainly not the only measure of the economic or inter-organizational impacts of R&D, as several of the authors noted. Indeed, they may not be the best measure.

Finally, compounding the force of these limitations in terms of the acceptability of econometric/statistical evaluation methods is the lack of transparency. Non-econometricians may not see how findings were generated. The use of econometric/statistical methods is not only complex, but also typically involves a large number of assumptions. Decision makers' uncertainty about those assumptions and the inner workings of the formulated models can deter acceptance of findings. Yet, as noted earlier, despite these limitations, econometric/statistical methods enable researchers to formulate and test critical hypotheses in ways that the other methods already discussed do not.

CHAPTER 8

Other Evaluation Methods Used by ATP

As reported in Chapters 4–7, the survey method, case study methods, and econometric/statistical methods have been applied extensively to the evaluation of ATP projects. This chapter presents several additional methods that have been used to a lesser extent—two traditional and three newly emerging methods.

The first two methods presented, expert judgment and bibliometrics, are well known evaluation methods. The last three methods presented—a unique approach to estimating knowledge spillovers using social network analysis, a cost index model for estimating consumer market spillovers, and a composite performance rating system for project and portfolio analyses—are still emerging. Their usefulness can be expected to increase as ATP and other programs gain experience with them and refine them further. The three emerging methods underscore a persistent goal of ATP's evaluation effort: to explicate new and improved analytical techniques for assessing ATP's program impacts. This effort reflects a realization that measuring the impacts of a program such as ATP challenges existing models and tools. Table 8–1 lists 11 studies illustrating in turn the use of expert judgment, bibliometrics, and the three emerging methods.

Expert Judgment

Like most public research and development (R&D) programs, ATP has used expert judgment in evaluating its program and general performance. In addition to using expert judgment as a stand-alone method, researchers have used expert judgment in various ways to support other evaluation methods, primarily by providing a basis for certain aspects of quantitative analyses. Examples from ATP evaluation studies show the use of expert judgment for assessment of

*Table 8–1. Ten Studies Using Expert Judgment, Bibliometrics, and Emerging Methods, including Cost Index, Social Network Analysis/Fuzzy Logic, and Composite Performance Rating System**

STUDY/AUTHOR	PURPOSE	APPROACH
Studies using expert judgment		
The Advanced Technology Program: Challenges and Opportunities (Wessner, 1999)	Broad, independent assessment of ATP; summary of symposium	Expert judgment informed by studies and analyses using other methods
The Advanced Technology Program: Assessing Outcomes (Wessner, 2001)	Broad, independent assessment of ATP; summary of symposium, condensed studies, findings and recommendations	Expert judgment informed by studies and analyses using other methods
Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage, Technology-Based Projects (Branscomb et al., 2000)	Inquiry into barriers to private sector investment in early-stage, high-risk technology development projects	Expert judgment informed by studies and analyses
Framework for Estimating National Economic Benefits of ATP Funding of Medical Technologies (Martin et al., 1998)	Estimation of Bass technology diffusion model in support of tissue-engineering case studies	Physicians and company reps supplied expert judgment on medical technology adoption
Advanced Technology Program Case Study: The Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing (CONSAD, 1997)	Estimation of key data needed for an economic case study	Heavy reliance on unnamed experts for key data
Studies using bibliometrics		
Development, Commercialization, and Diffusion of Enabling Technologies (Powell, 1996)	Counts of papers and patents as performance metrics	Data collected by ATP's Business Reporting System (BRS) survey
Performance of Completed Projects, Status Report 1 (Long, 1999)	Counts of papers and patents	Data collected by case study
Performance of 50 Completed ATP Projects, Status Report 2 (ATP, 2001)	Counts of papers and patents, and patent citations	Data collected by case study, patent trees constructed from Patent Office data

Table 8–1. (Cont'd)

STUDY/AUTHOR	PURPOSE	APPROACH
Studies using emerging methods		
Estimating Future Consumer Benefits from ATP-Funded innovation: The Case of Digital Data Storage (Austin and Macauley, 2000)	Estimation of market spillovers from investment in improvements in technology	Emerging method using a quality-adjusted cost index method
ATP and the U.S. Innovation System—A Methodology for Identifying Enabling R&D Spillover Networks with Applications to Micro-electromechanical Systems (MEMS) and Optical Recording (Fogarty, Sinha, and Jaffe, 2000 draft)	Identification and measurement of knowledge spillovers as a function of an organization's linkages	Emerging method using social network analysis and fuzzy logic
A Composite Performance Rating System for ATP-Funded Completed Projects (Ruegg, 2003)	0–4 star rating system to provide an overall performance measure against multiple program goals	Emerging method using a composite performance rating system constructed from indicator data.

*Note that five of seven studies using expert judgment are included; others being Branscomb, 2002; and Ruegg, 2003. Three of four studies using bibliometrics are included; the other being a report by Powell similar to that shown. Three studies — one of which (Fogarty, et al. 2000 draft) is included under Emerging Methods — used sociometric methods. The others using sociometric methods included Przybylinski, 2000 draft; and Darby, et al., 2002.

project and program performance. Use of the method for program relevance review, for benchmarking of organizations, programs, staff, or facilities, for personnel decisions, and for proposal review lies outside the boundary of this treatment.[243]

The first study presented illustrates the use of expert judgment to provide broad program assessment. The second study illustrates the use of expert judgment to

243 In its selection process, ATP uses peer review to assess project proposals against published criteria. A form of *ex ante* assessment for resource allocation, ATP's peer review selection process has been well described elsewhere and is not treated here. (See, for example, Alan P. Balutis and Barbara Lambis, "The ATP Competition Structure," in Charles W. Wessner, ed., *The Advanced Technology Program: Assessing Outcomes* (Washington, DC: National Research Council, 2000) pp. 175–188.) In addition, ATP, like most other government programs, engages an advisory committee to apply the expert judgment of its members to provide oversight of ATP's operations. This is a valuable and legitimate exercise of expert judgment in the public sector, but it is not treated here.

increase understanding of underlying program theory. Both studies were carried out by highly respected organizations capable of convening groups of experts to deliberate on complex ideas, and to draw conclusions and make recommendations based on that judgment. In these studies, the persuasive ability of the group providing the expert judgment is central to its success, and is based in large part on the reputation of the organizing body. In both cases, the knowledge and judgment of the experts are conditioned and informed by supporting testimony and studies brought to the attention of the experts and reflected in their study reports.

Two additional examples illustrate the use of expert judgment to overcome the absence of data needed for prospective impact estimation. In one of these examples, expert judgment plays a relatively minor role in support of a complex case study. In the other, expert judgment is the primary method used to develop project-level data used in the case study estimates.

The National Research Council's Assessment of ATP

In 1999, Congress directed ATP to arrange for a well-regarded organization with significant business and economic experience to conduct a comprehensive assessment of the program to determine how well ATP has performed in terms of achieving goals established by its authorizing statute.[244] In response, ATP requested that the National Research Council's (NRC) Board on Science, Technology, and Economic Policy (STEP) conduct an assessment of ATP as part of its broader review of government-industry partnerships for the development of new technologies.[245] In taking on this responsibility, NRC/STEP convened workshops and symposia, and commissioned a series of papers on ATP—all feeding into its ultimate findings and recommendations about ATP.

The important role of expert judgment is evident throughout the NRC assessment. First, the NRC study of ATP was managed by a distinguished multidisciplinary

[244]U.S. Senate Report 105–235.

[245]The resulting NRC review is organized into two reports, both edited by Charles W. Wessner, ed., and both published in NRC's Government-Industry Partnerships Series: Wessner, *The Advanced Technology Program: Challenges and Opportunities,* 1999; and Wessner, ed., *The Advanced Technology Program: Assessing Outcomes,* 2000.

steering committee assembled to oversee the broader study of government-industry partnerships.[246]

The two major symposia and a workshop organized by the steering committee convened additional experts and organized them in panels. The informed panelists were drawn from industry, government, academia, and the investment and financial communities. The symposia and workshops provided forums for experts to present and discuss information about the program, to express their perspectives, and to facilitate extensive audience discussion. Participants included critics, supporters, and those with neutral points of view. A body of independent analyses informed the deliberations.

The steering committee issued its core findings and recommendations in 2000. Among the findings was:[247]

> The program has set a high standard for assessment involving both internal and independent external review. The quality of this assessment effort lends credence to the program's evaluation of its accomplishments. (p. 6)

This statement suggests a strong connection and interplay between detailed program study and expert judgment in program assessment.

---

[246]The Steering Committee was chaired by Gordon Moore, the Chairman Emeritus of Intel. Other members included such notables in the field of economics and technology policy as Michael Borrus, Co-Director, Berkeley Roundtable on International Economics; Iain Cockburn, Professor of Commerce and Business Administration, University of British Columbia; Kenneth Flamm, Dean Rush Chair in International Affairs, University of Texas at Austin; James Gibbons, Professor of Engineering, Stanford University; William J. Spencer, Chairman, SEMATECH; Richard Nelson, George Blumenthal Professor of International and Public Affairs, Columbia University; and Patrick Windham, Stanford University. In addition, the project was overseen by members of the STEP Board, which included such notables in economics, business, and management as Dale Jorgenson, Chair, Frederic Eaton Abbe Professor of Economics, Harvard University; M. Kathy Behrens, Managing Partner, Robertson Stephens Investment Management; Vinton G. Cerf, Senior Vice-President, WorldCom; Richard Levin, President, Yale University; and Bronwyn Hall, Professor of Economics, University of California- Berkeley.

[247]Wessner, ed., *The Advanced Technology Program: Assessing Outcomes,* 2000.

Harvard-MIT Study of Technical Risk Management

Our second example of expert judgment illustrates use of the method to increase understanding of program fundamentals. Performed by Harvard's John F. Kennedy School of Government in collaboration with MIT's Sloan School of Management and the Harvard Business School, the study examined R&D barriers that keep private investors from funding early-stage, high-risk technology development projects.[248] Because the study was discussed extensively in Chapter 4, the treatment here will be brief, focusing on its use of expert judgment.

Principal investigators included Lewis Branscomb, Harvard University, and Kenneth Morse, Director of the Sloan School Entrepreneurship Center, with participation by Harvard Business School and MIT faculty. The project drew extensively on contributions of scholars and practitioners from business and venture capital organizations, government, and universities.

Like the NRC study, the Harvard-MIT study used the workshop/symposium format to convene experts, present the results of independent research and commissioned papers, stimulate discussion, shape key questions, and provide answers. The project report contains both the collection of contributed papers and the report of the project team.

Unlike the NRC study, however, the Harvard-MIT study does not present recommendations. Rather, it uses expert judgment to add to other methods that inform the program. In the words of the authors:

> The report of the project team integrates comments from participants in the two workshops, insights from the contributed papers, and references to related empirical and theoretical literature. Both sections of the report are intended to complement, rather than substitute for, surveys and statistical studies of a more demonstrably representative nature. Our discussion is intended to be realistic and practical, bringing forward the best understanding of the issues from academic studies and raising for government officials issues relevant to policy formation and program design. (p. 3.)

[248] Branscomb et al., *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-Based Project,* 2000.

Using Expert Judgment in Support of a Case Study

Often, expert judgment is used to support other methods. The illustrations provided here are drawn from two sources: a set of prospective economic case studies of medical technologies performed by Research Triangle Institute (RTI)[249] and a prospective economic case study of dimensional control technologies performed by CONSAD Research Corporation. Both of these are discussed in more detail in Chapter 6, where the focus is on the case study method.

Expert Judgment for Prospective Evaluation of Medical Technologies

RTI's seven case studies all dealt with new tissue engineering technologies, which had not yet been commercialized at the time of the study. To estimate prospective private and social benefits, the analysts needed to know the number of patients to be treated with each new technology each year if it were successfully implemented. The plan was to project the market penetration of each technology by using a widely used, standard Bass diffusion model, depicted in Figure 8–1 and named after Frank Bass who described it in 1969.[250] According to the researchers:[251]

> To estimate the Bass model, we needed to collect information about the early penetration of the technology and its maximum market penetration after 10 years. Because these technologies have not yet been commercialized, we asked experts in the treatment of each disease to provide their estimates of these parameters. We asked them to predict market penetration in the first several years after introduction and the ultimate market penetration after 10 years. We used these predictions to estimate a Bass diffusion model, which provided 10-year forecasts of market penetration.

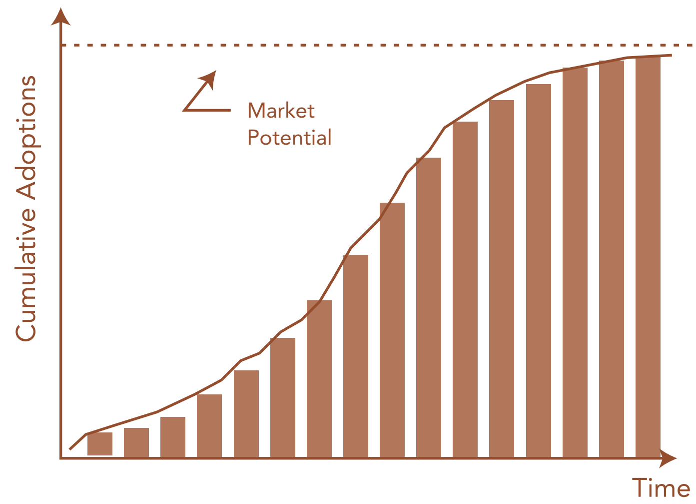
In the case of RTI's analysis of Aastrom Biosciences' human stem cell expansion technology and three other technologies under development, the approach was to

[249] Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998.

[250] Bass, "A New Product Growth Model for Consumer Durables," 1969.

[251] Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, pp. 1–9 to 1–10.

Figure 8–1. The Classic Bass Diffusion Curve



The Bass Diffusion Curve reflects the fact that a new technology is typically not adopted by all potential users at one time, but rather diffuses into use over time. Adoption is shown to increase at an increasing rate for a period and then to level off as market saturation occurs, generating an s-shaped curve.

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, p. 2–27.

interview physicians to obtain data for the Bass diffusion model. RTI identified the physicians for interview as experts in the treatment of the diseases in question after consulting with the innovating companies, relevant medical associations, and other physicians. For three additional cases for which less in-depth case studies were performed, the researchers interviewed company representatives for their expert judgment to obtain the provided diffusion estimates. Although both the physicians and company representatives were considered experts by the study, it was implied that the physicians were higher-level experts in the subject matter than the company representatives. The definition of an expert, therefore, has a subjective element and may vary even within a given study.

Figure 8–2. Interview Guide Used by RTI Researchers to Compile Judgments from Physicians Who Are Expert in Treating the Relevant Diseases

Figure A–6. Physician Interview Guide

This interview is part of a study that RTI is doing for the National Institute of Standards and Technology (NIST). NIST has asked us to talk with clinical experts about the expected market acceptance of a number of new biotechnologies.

Introduction

1. First, can you please tell me about your particular affiliation?
   a. research organization, hospital or clinic, private or group practice, government, etc.
   b. type of patient base you see (if appropriate)
   c. number of years you have been in your present position, current title
   d. your affiliation with the biotechnology company

Estimating the Eligible Population

Please examine the clinical profile of the treatment, including the target patient profile and the costs and outcomes of the treatment.

1. In thinking about the application that this therapy is intended for according to the profile we sent you, what groups of patients do you believe are eligible to receive the treatment?
   ✓ describe patient cohorts (e.g., by age, severity of disease, type of disease, receiving a certain treatment, etc.)
   ✓ Would these patients all be eligible for the defending treatment as we have defined it on the profile?
2. Do you think the population of eligible patients will change over time, or will the number of eligible patients remain constant over the next 10 years? How will it change?

Potential Barriers to Market Penetration and Market Penetration

1. What do you view as some of the bariers to this treatment's widespread use? For example:
   ✓ physicians
   ✓ insurance companies
   ✓ patients
   ✓ hospitals
   ✓ costs

Cont'd on next page

Figure 8–1. (Cont'd)

2. Who do you think will be most influential in determining whether this treatment becomes widely used or not (e.g., physicians, hospitals and managed care formularies, insurance companies, patients)?

3. Given that patients in group A (as you have defined it) are eligible for this treatment, and taking into account the barriers we just discussed, what percentage of the patients in group A do you think will actually receive the treatment?

   Please provide this percentage for each of the first 5 years that the treatment is available.

   ________% ________% ________% ________% ________%

4. Given that patients in group B (as you have defined it) are eligible for this treatment, and taking into account the barriers we just dicussed, what percentage of the patients in group B do you think will actually receive the treatment?

   Please provide this percentage for each of the first 5 years that the treatment is available.

   ________% ________% ________% ________% ________%

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, pp. A–8 to A–9.

For the physician interviews, RTI developed clinical profiles for the technologies and provided them to the physicians prior to the interviews. They did not identify the companies involved to the physicians. They sent a set of questions to the physicians in advance of the interview and prepared an informal interview guide that was used for the subsequent telephone interviews of the physicians. Figure 8–2 replicates the interview guide used to solicit expert judgment from the physicians. Table 8–2 shows the data collected from physician experts for one of the technologies studied, Aastrom Biosciences' human stem cell expansion system.

Table 8–2. Data Sample Collected from Expert Physicians and Used to Estimate the Bass Technology Diffusion Model

	Percentage of population receiving treatment					
Eligible population	Year 1	Year 2	Year 3	Year 4	Year 5	Market cap
Stem cell expansion						
Autologous BMTs	4	10	15	25	—*	—*
Multicyclic chemotherapy	10	20	25	30	40	—*
Autologous BMTs	1	5	10	10	10	100
Multiple-course cancer therapy	1	5	10	20	20	20
Cord blood transplants	1	10	20	50	50	100
Chemotherapy + autologous stem cell support	3	8	15	25	35	—*
Chemotherapy + cord blood support	3	8	15	20	20	100
Dose intensive therapy	3	8	15	25	40	100
Chemotherapy and allogeneic stem cell support	3	8	15	20	20	100
Biopolymers for tissue repair						
Adults (five fracture sites)	1	3	5	10	15	25
Pediatric (all fractures)	2	6	10	20	30	75
Adults (five fracture sites)	25	40	55	70	75	75
Adults	10	10	10	20	20	20
Pediatric	10	10	10	10	10	10
Living implantable microreactors						
Type I diabetics	1	5	10	10	10	10
10% Type II diabetics	1	10	15	15	15	15
Type I children under 10 years of age	2	55	2	5	10	100
Type I over puberty and with complications	20	2	30	40	50	100
Type I over puberty and with no complications	10	25	10	20	30	100
Type II insulin-dependent with disease for > 10 years	2	2	2	5	10	100
Type I diabetics	3	7	15	30	50	95
Type II diabetics (ins-dep.) < age 50	1	2	4	20	25	25

* Denotes missing value.

Source: RTI, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies,* 1998, pp. A–11 to A–12.

It is apparent in the study report that the researchers took special care in collecting and documenting the rendering of the expert judgments in their in-depth case studies. This appears to contrast sharply with the approach taken in the next example, where the use of expert judgment is stated, but the approach and documentation remains a "black box," unavailable to the reader.

Expert Judgment for Prospective Evaluation of Dimensional Control Technologies

A second example of using expert judgment to fill in missing data in prospective case study analysis is found in CONSAD's case study of technologies to reduce dimensional variation in automotive bodies, the so-called "2mm project" funded by ATP.[252] The technologies in this case were further along than in the previous medical technologies cases. In fact, according to the researchers:

> Portions of the technologies and methodologies developed under the 2mm Project already have been transferred into operation at five motor vehicle assembly plants...Each of these five assembly plants has realized or exceeded the goal of achieving 2.0 mm total dimensional variation for BIWs[253] ...Thus, there is evidence that the results of the 2mm Project are being successfully commercialized within the automobile manufacturing industry. (p. 14.)

The researchers noted, however, "Because the technologies...are new, their impacts on industrial production and economic activity are not yet revealed in the extant empirical data on industrial performance."[254]

In the absence of published data at the industrial sector level, CONSAD researchers relied heavily on expert judgment in making their economic estimates of impact. The expert judgment appeared to be informed by empirical data but the extent to which this was true was not revealed. They cited the proprietary

[252]CONSAD Research Corporation, *Advanced Technology Program Case Study: The Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing,* 1996.

[253]BIW refers to body-in-white.

[254]Ibid., p. 17.

and confidential nature of in-house data from plant implementation of the technology as the reason for concealing exactly how and to what extent it may have come into play in the estimates. According to the CONSAD report:

> Initial estimates of some of the economic impacts of the 2mm Project are ... based on expert judgments of the expected future changes in costs and final demands that will result from the adoption of technologies developed by the 2mm Project in automobile assembly plants... These judgments were obtained by CONSAD 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 for individual plants and firms adopting technologies that have resulted from the 2mm Project, are not cited because of the proprietary and confidential nature of the data about current and expected cost savings and expected product demands. (p. 17)

CONSAD's approach constitutes a sweeping use of experts to estimate economic impacts, with only general references in support of the estimates. At best, the study reveals the types of impacts identified, explains the logic behind each impact, and plugs in the expert-supplied dollar amount per unit. Thus, for estimated benefits of automotive production cost savings, the report states "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 new production costs...at those facilities have been reduced by approximately $75 per vehicle..."[255] Similarly, experts estimated a range of benefits for automotive maintenance cost savings, a range of changes in market share associated with improvements in automobile quality, and the year in which the 2mm technology was expected to be adopted in all GM and Chrysler assembly plants. The estimates of production cost savings and maintenance cost savings drove the study's microeconomic estimates of impact, and the estimated change in market share due to quality improvements drove the study's macroeconomic impact estimations using the Regional Economic Modeling, Inc., (REMI) model.

[255]Ibid., p. 20.

According to the report, "The experts who provided data and judgments regarding estimated changes in market share referred to past instances when a short-term change in the perceived quality of an automobile model resulted in a shift in market share for the particular model relative to competitive models."[256] But no reference data and no specific references to the literature documenting these past instances are provided in the report. Presumably, they are proprietary or confidential.

Citing experts knowledgeable about the substance of the technologies, and experts knowledgeable about the industries and markets, the study states:

> The plausibility of the judgments provided by the two groups of experts has then been evaluated by examining the coherence among the judgments provided by the various experts in each group. In addition, to the degree possible, the judgments have been compared to the available empirical data on the outcomes of the initial applications of the technologies in actual industrial situations...and to published evidence on the outcomes of applying similar technologies in comparable circumstances. (p. 18)

But these referenced checks across the groups of experts and the comparisons to empirical data and published evidence on similar technologies are not revealed to the reader beyond the assertion that they were done. In this study, the findings rest to an extraordinary extent on expert judgment, for which it is impossible for the reader to judge the care that went into its collection or its quality.

Bibliometrics

As defined in Chapter 2, the bibliometrics method encompasses a family of techniques for assessing the quantity, dissemination, and content of publications and patents—both important knowledge outputs of ATP projects. As indicated throughout this report, adding to the nation's technical knowledge base is one of the central missions of ATP.

Surprisingly, perhaps, ATP's use of bibliometrics during most of its first decade has been limited to counting papers and patents and the organizations producing

[256]Ibid., p. 22.

them, and to an emerging use of patent trees to capture patent-to-patent citation patterns for completed projects. Publication-to-publication and patent-to-publication citation analysis has not yet been done at the time of this report, and content analysis of published documents also has not yet been done. Econometric studies have made extensive use of patent citation data as a proxy for knowledge spillovers. (See Chapter 7.)

One factor accounting for ATP's limited use of bibliometrics thus far has been the time it takes for patents to be awarded and citation databases to reflect program activity. Thus, the technique could be more profitably applied now than earlier in the program's history. Another limiting factor may have been stakeholders' emphasis on the program's ability to demonstrate quantitative measures of economic impact and direct, tangible short-term output indicators such as number of patents granted.

This section covers two ways ATP applied the bibliometrics method during its first decade. First presented is the quantification of publication and patents as measures of program outputs. Second presented are patent citation trees showing dissemination of knowledge for completed projects.

Counting Publications and Patents

ATP began compiling counts of papers published in professional journals and presented at conferences when it launched its Business Reporting System (BRS) in 1993.[257] It used the data to show that the projects were disseminating non-proprietary information. Table 8–3 shows the counts of papers and organizations and projects reporting papers on December 31, 1996, from 210 ATP projects funded between 1993 and 1995.

Counts of papers, as well as patents, were also a feature of the data compiled in conjunction with the Status Reports described in Chapter 6.[258] A template used

[257]See Chapter 5 for a description of BRS. Prior to the collection of counts of papers, surveys of program participants had queried them about their intentions to publish and to patent.

[258]See Long, *Performance of Completed Projects, Status Report 1,* 1999, p. 12; and Advanced Technology Program, *Performance of 50 Completed ATP Projects, Status Report 2,* 2001, p. 16.

Table 8–3. 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 conference papers were presented per project. Thirty-six percent of the projects produced at least one professional journal article; 53% of the projects produced at least one conference paper.

Source: Powell and Lellock, *Development, Commercialization, and Diffusion of Enabling Technologies, Progress Report,* 1996, p. 41.

to guide uniform data collection in support of the Status Reports includes the number of papers published or presented, as well as data for patents granted and a rough count of patents filed but not yet granted.

Figure 8–3 shows the summary data for papers and presentations from the second volume of Status Reports covering 50 completed projects. These data were one input to scoring project performance.

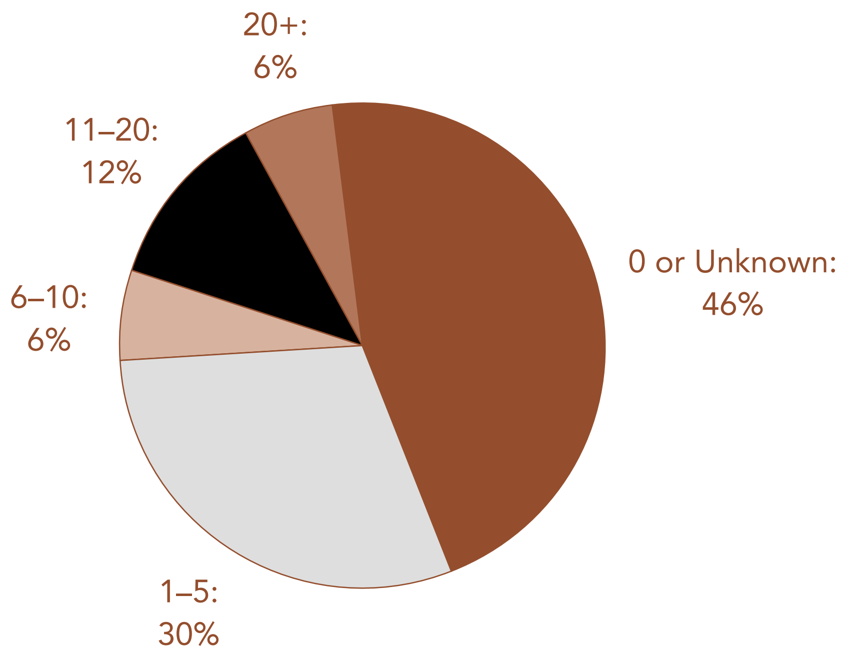
Figure 8–4 shows data for patent filings. These data were another input to scoring project performance.

Patent Citation Trees

While patent citations have been used extensively as data input to the econometric studies described in Chapter 7 and the social network analysis study presented in Chapter 8, bibliometric citation analysis of ATP projects has been limited at the time of this study to the construction of "patent citation trees" for completed projects, available in ATP Status Report 2.[259] Patent citation trees are

[259]Advanced Technology Program, *Performance of 50 Completed ATP Projects, Status Report 2,* 2001.

Figure 8–3. Distribution of Projects by Number of Publications and Presentations



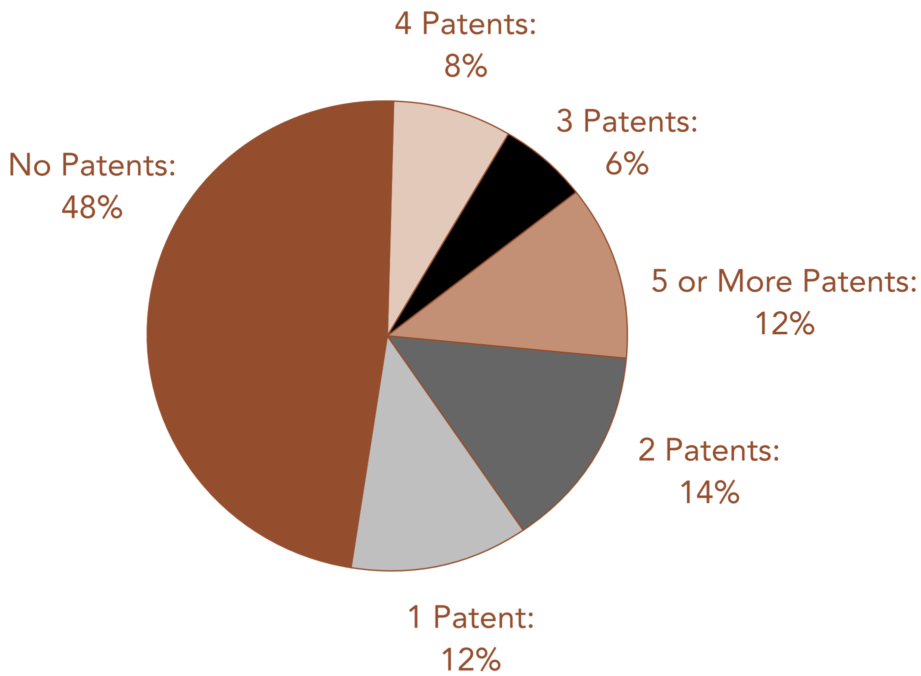
Source: Advanced Technology Program, *Performance of 50 Completed ATP Projects, Status Report 2*, 2001, p. 16.

diagrams that show forward citing of the patents generated by, in this case, ATP-funded completed projects.

The ability to construct a patent tree rests on the fact that each published patent contains a list of previous patents and scholarly papers, establishing the prior art as it relates to the invention in question. Citations can be used to track the dissemination of technical knowledge to subsequent publications and patents. Patent citation trees show visually the pattern of dissemination of patents granted. As described in ATP, *Performance of 50 Completed ATP Projects, Status Report 2*:

> By following the trail of patents referenced in subsequent patents back to the patents granted to the ATP-funded projects, it is possible to construct

Figure 8–4. Distribution of Completed Projects by Number of Patents Filed

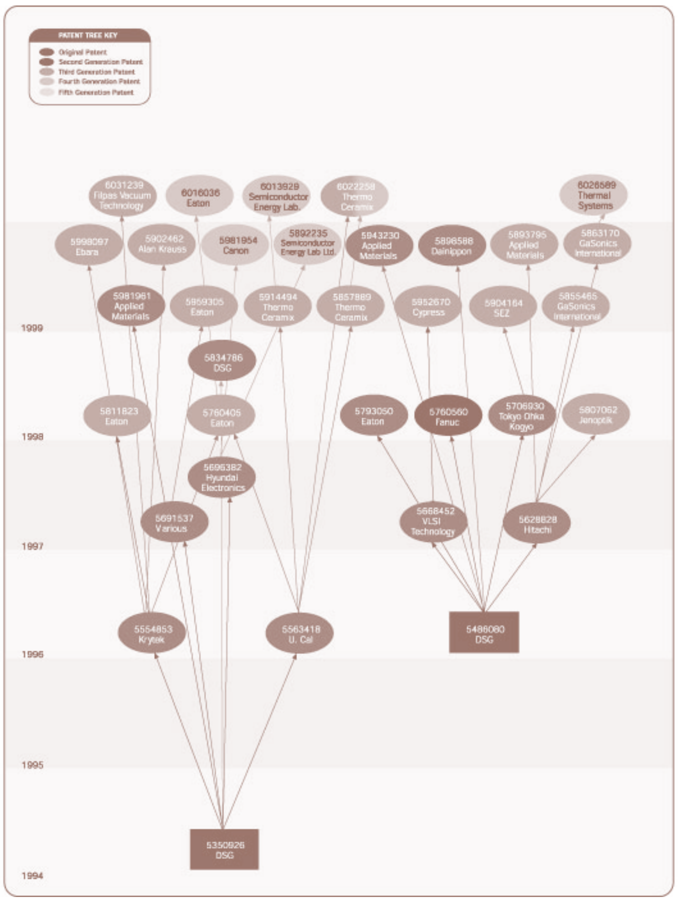


Source: Advanced Technology Program, *Performance of 50 Completed ATP Projects, Status Report 2,* 2001, p. 10.

> what looks much like an inverted genealogy tree, with parents (the patents of ATP-funded projects), children (patents that refer directly to the ATP-related "patents"), grandchildren, and so on. (p. 20).

Figure 8–5 shows a patent tree for one of the first 50 completed ATP projects, a project to develop wafer ion-implantation, carried out by Diamond Semiconductor Group (DSG). At the time the patent analysis was performed, DSG had received two patents and filed for two additional patents related to its ATP project. The focus of the illustration here, Patent 5,486,080, "High speed movement of workpieces in vacuum processing," was granted to DSG in 1996. The Status Report provides the following account of subsequent citing of the patent:

Figure 8–5. Illustrative Patent Tree for ATP



Source: Advanced Technology Program, *Performance of 50 Completed ATP Projects, Status Report 2,* 2001, p. 121.

The following year, 1997, two patents—one granted to VLSI Technology and the other to Hitachi—cited the DSG patent. In 1998, three additional patents—granted to Eaton, Fanuc, and Tokyo Ohka Kogyo—directly cited the DSG patent. An additional patent—granted to Jenoptik, cited

> the Hitachi patent—thus indirectly citing the DSG patent. In 1999, two additional patents—granted to Applied Materials and Dainippon—directly cited the DSG patent, and five new patents indirectly cited the DGS patent. Four of these citations are once removed: a patent granted to Cypress, a second patent granted to Applied Materials, and two patents granted to GaSonics International; and one is twice removed: a patent granted to SEZ. (p. 11)

Additional branches may spring up over time as subsequent patents cite either the DSG patent or one of the subsequent patents that cite the DSG patent. Additional patents granted to DSG, and attributable to the ATP project, also generated subsequent citations.

Some of the patent trees portrayed in the Status Report are for projects that appeared to have reached a stand still in terms of follow-through activity by the project innovators. These patent trees serve as reminders that knowledge spillover may result from projects that have not shown much commercial progress or related market spillovers. "Although representing only one aspect of knowledge dissemination, the patent trees extend our understanding of the influence of the new knowledge created on others."[260] As was indicated in Chapter 3, the frequency of citations suggests, though imperfectly, the significance of a patent in terms of its relevance, extent of dissemination, and impact.

Emerging Methods: Using Social Network Analysis to Identify Knowledge Spillovers

Spillovers have a central role in justifying public support of R&D, but are difficult to identify and measure. Improving the methods of identifying and quantifying R&D spillovers is an important goal for a public R&D program. This section discusses a promising new method of identifying and measuring knowledge spillovers from R&D.

[260] Ibid., p. 11.

The earlier discussion of the study by Darby et al., introduced the concept of research networks or systems, that is, patterns of interactions and communications among organizations—firms, universities, other laboratories—that reveal the generation and exchange of scientific and technological knowledge. An implicit hypothesis linking the concepts of spillovers and research networks is that the closer and denser the system of linkages among various organizations, the greater the likelihood of knowledge spillovers.

Adam Jaffe, Brandeis University, who prepared a seminal background report on spillovers for ATP, teamed with Michael Fogarty, Portland State University, and Amit Sinha, Case Western Reserve University, to develop a new method of assessing knowledge spillovers using social network analysis.[261] In itself, ATP's support of this work constitutes a form of knowledge spillover, as the technique has potential applicability for other federal and state agencies in evaluating their R&D and other knowledge-generating programs.

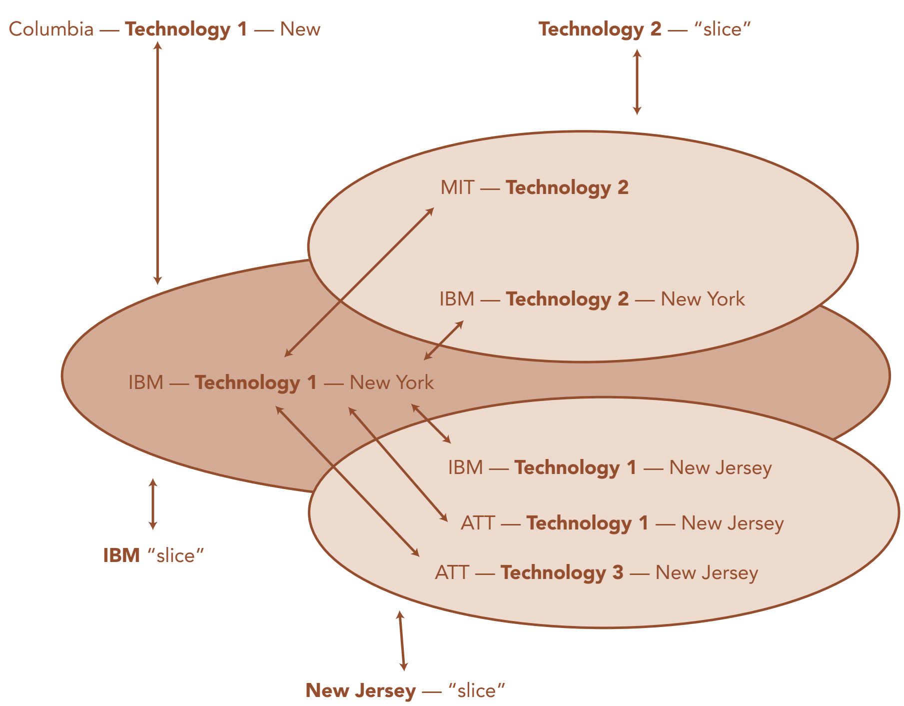
This emerging method uses systems analysis and fuzzy logic to analyze R&D knowledge spillovers within networks of R&D organizations. Though still in its infancy, the method holds promise for retrospective evaluation as well as prospective selection of projects with above-average knowledge spillover potential. Furthermore, the method, which identifies spillover patterns across organizations, technological areas, geographic regions, and industries, permits the separation of knowledge spillovers into those realized by the United States and those realized by other countries. The researchers noted that by funding projects involving particular organizations and technologies ATP would implicitly pick networks with implications for expected social benefits.[262] An important theoretical aspect of their work is that it highlights the fact that a firm's value as a source of knowledge spillovers "depends on its ability to learn from its external environment...."[263] Figure 8–6 illustrates the basic conceptual framework of the R&D network analysis method.

261Michael S. Fogarty, Amit K. Sinha, and Adam B. Jaffe, *ATP and the U.S. Innovation System—A Methodology for Identifying Enabling R&D Spillover Networks with Applications to Micro-electromechanical Systems (MEMS) and Optical Recording,* Draft report, ATP, 2000.

262Ibid., p. 52.

263Ibid., p. 35.

Figure 8–6. Conceptual Framework of the R&D Network

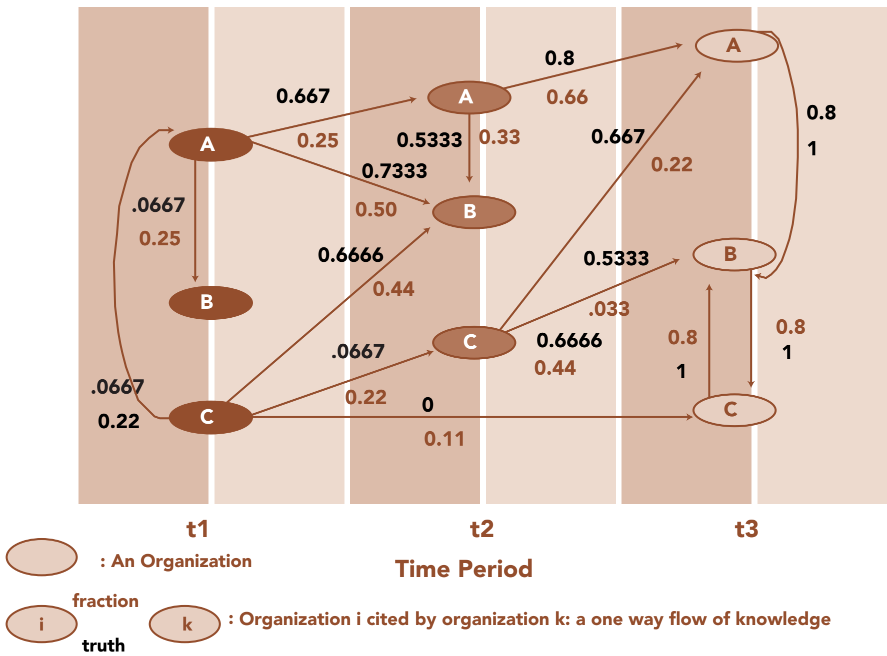


Depicted are the interactions of an organization (an IBM laboratory), working in a specific technology area (denoted by a patent class), located in a specific geographical region (New York), with other parts of the relevant technology network. For each node in the system, patent citations are used to measure its pair wise interaction, in both directions, with another node. In addition, once the strength of pairwise interactions is measured, it is possible to measure the system influence of each node. "The system influence of each node results from the strength of its interaction with other nodes, compounded by the strength of the interaction of those nodes with other nodes." (p. 26)

Source: Fogarty et al., *ATP and the U.S. Innovation System—A Methodology for Identifying Enabling R&D Spillover Networks with Applications to Micro-electromechanical Systems (MEMS) and Optical Recording,* 2000.

Figure 8–7 illustrates a more sophisticated version of the analysis, as it incorporates the strength of the relationship between organization A and other R&D laboratories.

Figure 8–7. All Citations are not Equal: A One-Way Flow Illustration



Source: Fogarty et al., *ATP and the U.S. Innovation System—A Methodology for Identifying Enabling R&D Spillover Networks with Applications to Micro-electromechanical Systems (MEMS) and Optical Recording*, 2000.

Patent Citations as a Proxy for Knowledge Flows

The new method uses patent citations as a proxy for flows of scientific and technical knowledge. The researchers acknowledged that there is “noise” in patent citations data[264] and that “for any given patent citation, there is a non-trivial chance that no spillover occurred.”[265] These shortcomings notwithstanding, they

[264]They point to a less critical view of patent citations that sees them as providing “direct observations of knowledge spillovers...” Ibid., p. 14.

[265]Ibid., p. 20. “Noise” in the data refers to the fact that patent citations are imperfect indicators of flows of knowledge. For example, a patent analyst may add a citation as legal protection without an actual occurrence of communication expressing a knowledge flow underlying the citation.

asserted, "The probability of a spillover, conditional on a citation being observed, is significantly greater than the unconditional probability."[266]

Though previous studies used patent citations as a proxy for knowledge spillovers,[267] this study went beyond those studies by analyzing patent citations from a systems perspective; that is, in terms of citing and sourcing entities that constitute "networks of communication and influence within the innovation system."[268] At the crux of this approach is the idea that "spillovers that one organization gets from another depend not only on the communication between the two organizations, but also on the communication that each engages in with other organizations."[269] In describing the difference between their approach and previous work, the researchers stated:

> On the one hand, the traditional approach treats the spillover process as linear and additive. If researcher B gets 10 spillover units from researcher A and 5 spillover units from researcher C, then B has received 15 spillover units. In contrast, using the systems approach, we think of researcher B as residing within a mutually interconnected network. Her productivity will be affected by the overall vitality of knowledge flow in that network and the strength of her connections to the network generally. A researcher is well connected to the network by being well connected to other researchers, who are themselves well connected to the network. (p. 25.)

The researchers considered an increase in the rate of system citations to the ATP award winner to provide a measure of the direct spillovers from the award winner. They pointed to overall increases in flows of knowledge through the network as signaling a broader influence of ATP. In their words, "[a funded project] establishes and strengthens communication links among the joint venture members and perhaps with other firms."[270]

---

[266]Ibid., p. 20.

[267]The study provides a review of prior research using patent citations. Prior research, according to Fogarty et al., has used "ex-post citations to infer the 'quality' or 'importance' of the cited inventions," and "citation patterns to make inferences about the nature and direction of knowledge spillovers." Ibid., p. 15.

[268]Ibid., p. 5.

[269]Ibid., p. 20.

[270]Ibid., p. 8.

The methodological advance attempted in this study is the move from pairwise relationships among sets of variables—researchers, research organizations, regions—to a "systems" perspective. The systems perspective provides for a cascading sequence of interactions among R&D performers, again measured in terms of patent citations. Their study analyzed the impact of patent A not only on patent B, which cites A, but on patents C and D that cite B, and thus A by inference. It also estimated the differential importance of citations based on the importance of the organizations that cited them. They described their overall approach as follows:

> Fundamentally, the systems methodology is based on the idea that the influence of organizations can be understood—and measured—by examining the place of each organization within an R&D network.... [I]nfluential organizations are those that are connected to and communicating with a lot of other organizations, and particularly a lot of other influential organizations. They represent important nodes in the communication system, meaning that a large fraction of the overall information flow in the network passes through them. (p. 22)

Application of the Systems Method, Network Analysis, and Fuzzy Logic Techniques to Measure Communications Flows

The researchers used fuzzy logic to model varying degrees of connectedness of nodes within the network, calculating a ***truth value,*** a value between 0 and 1, to provide a "measure of the magnitude of interaction for every pair of nodes."[271] ***System influence*** is the measure of the overall impact of a node, built iteratively with a fuzzy-logic algorithm.[272] Since each node is described in terms of its organization, technology, and geographical location, it is possible to "construct slices through the multidimensional system along any dimension of interest."[273] The basic unit of analysis in the study is the R&D laboratory, which is located in a specific region, working on a specific technology, in a particular time period. Patent citations are treated as a proxy or indicator variable for "communications" among

[271] Ibid., pp. 29–30.

[272] Ibid., p. 30.

[273] Ibid., pp. 30–31.

R&D laboratories. The researchers assumed "the tightness of the link between citations and communications does not differ systematically across the different dimensions of organization, technology and geography."[274] They explained in the report how they calculated each of the measures:

> The fuzzy methodology allows us to develop indicative membership measures between 0 and 1 representing the strength of interaction between any pair wise combination of R&D labs, specific to organization, technology, and region. Our systems model then builds the system iteratively incorporating the first, second, and then the third level of diffusion of spillovers. The result is a hierarchical R&D network system. (p. 47)

Experimental Application of the Method to Investigate Knowledge Spillovers in Two Technology Areas

The researchers' first application of the new method was to map research networks underlying two areas: micro-electromechanical systems (MEMS) and short-wavelength sources for optical recording (SWAT). The MEMS analysis emphasized the network dimension of organizational space, and the optical recording analysis emphasized technological space. The researchers did not attempt to measure knowledge spillovers, though they pointed to this potential use of the method after further development.

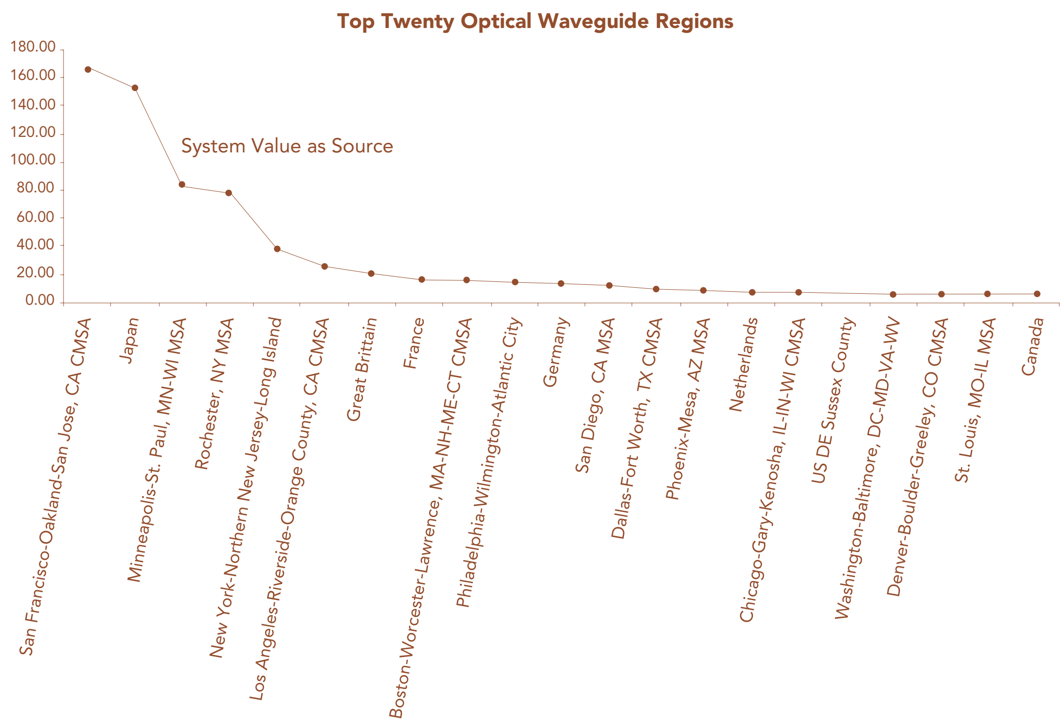
A core database of about 1,200 MEMS patents and citations to the patents underlies the MEMS analysis. A comparison of organizational rankings based on simple counts of citations, versus rankings based on the new network analysis, showed a difference in the expected R&D spillovers. Using their systems approach, the researchers identified the patents cited most frequently, the leading MEMS organizations ranked by systems influence, and the geographic centers of R&D. Their study identified the top five MEMS technologies, the most influential segments of the MEMS network, the key universities, and the key regions.

SWAT technology had been the focus of a joint venture funded in part by ATP in 1991, and led by the National Storage Industry Consortium (NSIC). The project

[274] Ibid., p. 28.

was intended to respond to Japanese domination of the optical recording market at the time, which in turn was seen as a threat to U.S. market share in the data storage device industry. For the SWAT analysis the researchers identified leading researchers, patents, and citations. By applying the new method, they identified and ranked the top 20 optical wavelength technologies, organizations, and regions. Figure 8–8 shows the optical wavelength technologies to be concentrated in a few regions.

Figure 8–8. Top Twenty Optical Waveguide Regions



Source: Fogarty et al., *ATP and the U.S. Innovation System—A Methodology for Identifying Enabling R&D Spillover Networks with Applications to Micro-electromechanical Systems (MEMS) and Short-Wavelength Sources for Optical Recording*, 2000.

Fogarty et al., described their work on optical recording as serving to illustrate the potential of their methodology, not as an evaluation of SWAT, for which considerably more information and more current data would have been needed. Their findings indicated that ATP had good reason to expect that its support of SWAT would generate a large volume of R&D spillovers. Supporting this conclusion is their finding that the most influential organizations in the network were U.S. organizations, two were members of the ATP joint venture, several were also members of NSIC, and the joint venture was led by NSIC.[275] The researchers observed that the ATP funding in this case supported research of an enabling technology carried out by well connected U.S. organizations, leveraging federal support of basic research, and reaching a large market.[276]

Significance and Status of the New Method

By placing knowledge spillover analysis within the context of R&D networks, the Fogarty et al., method of measuring knowledge spillovers made a significant advance over other ways of measuring knowledge spillovers. It "provides a framework for developing ATP strategies to maximize spillovers, and suggests an approach to evaluating ATP projects."[277]

According to the authors, the approach can be used to analyze the evolution of networks surrounding particular industry-based technologies, and thus answer ATP program design and project selection questions, such as, "Are university members becoming less important sources while companies become increasingly important network members?"[278] It can also be used to identify which of a set of technology clusters within a larger technology area are more likely to spur advances in other technologies.

The researchers pointed out that the fuzzy logic method would not permit the drawing of statistical inferences or the standard statistical testing of hypotheses.[279]

---

[275]Even though only a minority of its members participated in the joint venture, NSIC represents a potentially very powerful mechanism for magnifying R&D spillovers from the joint venture.

[276]Ibid., p. 80.

[277]Ibid., p. 93.

[278]Ibid., p. 44.

[279]Ibid., p. 93.

They argued that *ex post* evaluation, to measure knowledge spillovers, is its most straightforward application. They described potential use of the method for project selection as more uncertain, "but still worth exploring."[280] They speculated that software and a database might be developed to allow routine assessment of the strength of applicants' system influence. They also suggested that the method might be used to develop a way to assess synergistic impacts of projects.[281] Thus, the researchers' suggestions for further research are aimed at advancing the new method to overcome existing limitations and make it practically applicable. If this could be done, the method would offer an important new way of obtaining more information about a central impact of publicly funded R&D, the generation of knowledge spillovers.

Emerging Method: Using the Cost Index Method to Estimate Social Benefits

Estimation of the social benefits derived from ATP-sponsored technological innovations constitutes an important part of its evaluation program, because such estimates help answer policy questions about the magnitude of the return to the nation on the public investment in ATP-funded projects. David Austin and Molly Macauley, senior economists at Resources for the Future, developed a new method for estimating "social benefits from innovations in inputs in the service sector, where real output is not directly observable."[282] To develop the model, Austin and Macauley drew on earlier work by Stanford University's Timothy Bresnahan.[283] They extended Bresnahan's method, which was aimed at retrospective evaluation, to make it appropriate for prospective analysis.

Their technique involves a more comprehensive, theoretically grounded, quantitatively flexible means of estimating consumer welfare gains than provided for in earlier ATP studies. However, the technique has greater demands for data,

[280] Ibid., p. 95.

[281] Ibid., p. 97.

[282] David Austin and Molly Macauley, *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage,* NIST GCR 00–790 (Gaithersburg, MD: National Institute of Standards and Technology, 2000.)

[283] Timothy Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review,* 76(4): 742–755, 1986.

involves a larger number of assumptions about the values of unknowns, and, because of its complexity, requires explicit attention to the sensitivity of findings to assumed values. Therefore, it simultaneously runs the risk of being dependent on the modeler's art and of being opaque to decision makers. As the authors noted:

> The results are clearly no stronger than the assumptions underlying the model. The probabilistic parameters allow for unforeseen technological developments, however, and one of the model's strengths is that it incorporates all relevant information and varies all of the parameters simultaneously. (p. 18)

Austin-Macauley's Cost-Index Approach

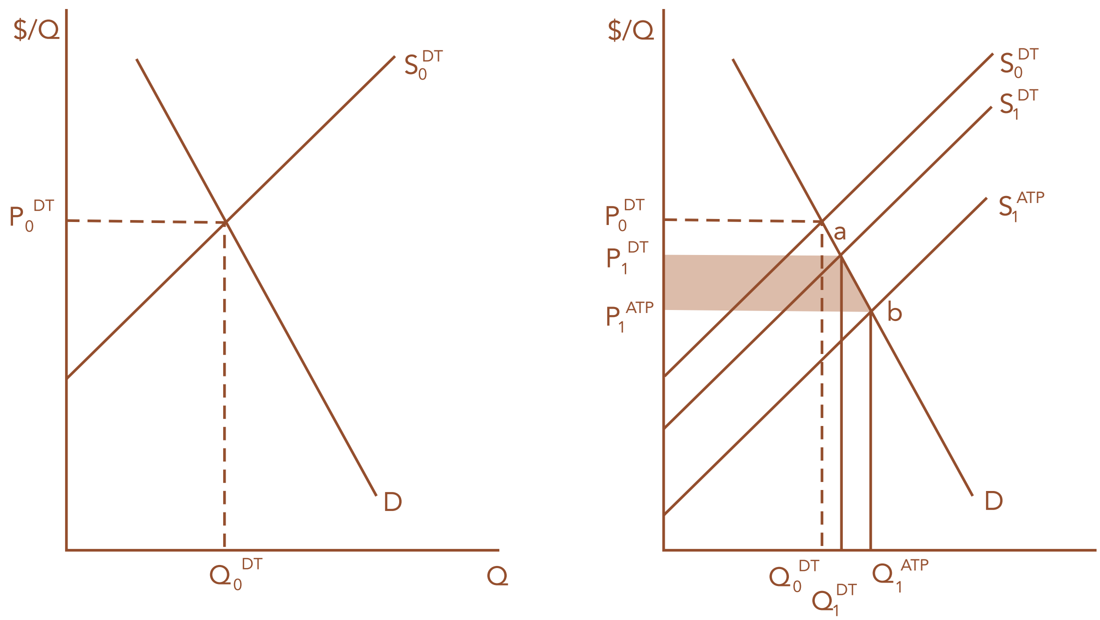
The basic working of the model is illustrated in Figure 8–9, where introduction of a new innovation shifts the supply schedule from S_o^{DT} (the pre-innovation supply of the defender technology) to S_1^{ATP} (the after-ATP supply of the new technology). Allowance for continuous improvement in the defender technology, however, causes a shift in the defender technology supply schedule to S_1^{DT}. For the ATP-sponsored technology to yield economic benefits requires that S_1^{ATP} be lower, or to the right, of the improved defender technology, S_1^{DT}.

The new technology is assumed to be an input into the production of goods and services by downstream buyers. Under competitive conditions in these downstream markets, derived demand for the technology reflects consumer demand, and, according to the researchers, "...the cost index will correctly estimate the welfare gain."[284] If downstream markets are not competitive, then the cost index yields a lower bound estimate of consumer gain. The cost index approach "compares observed price and performance for an innovated product against hypothetical, best available price and performance had the technical advance not occurred."[285]

[284] Austin and Macauley, *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage,* 2000, p. 5.

[285] Ibid., p. 1.

Figure 8–9. Derived Demand for New Technologies: Illustration of Net Surplus Change



Source: Austin and Macauley, *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage,* 2000, p. 6.

The researchers noted three major sources of randomness in the model's parameters: variability in manufacturing and market conditions, imperfectly observed data, and "most importantly, uncertainty about future outcomes."[286] Thus, rather than use single values, they incorporate in the model probability distributions of several parameters, including off-the-shelf nominal prices, quarterly rates of change in these prices, quality differences between performance attributes of the innovation and defender technologies, market size, adoption rates, personal consumption expenditures, and shadow prices.

[286]Ibid., p. 13.

Testing the Austin-Macauley Model

Austin and Macauley tested their model for two digital storage technologies funded in part by ATP. Both technologies were aimed at achieving much faster writing and retrieval of digital data than possible with defender technologies, and one also offered a large increase in storage capacity.

Data elements used in constructing the cost index included "estimated downstream digital data storage (DDS) expenditures as a share of total personal consumption expenditures, off-the-shelf DDS prices; differences in the technical attributes of the defender technologies and the innovations; marginal consumer valuations of these differences; quality-adjusted prices reflecting these valuations; and market rate of adoption of the innovation."[287]

Data for several of these parameters were collected from structured interviews in 1998 with the leaders of the industry teams conducting the ATP-funded research. Table 8–4 reproduces the interview instrument.

The researchers generated estimates of shadow prices to determine the imputed value of the improved performance attributes associated with the two new technologies using a hedonic regression model of digital data storage drive attributes. They obtained data for this procedure from the websites of manufacturers and advertisements in magazines.[288]

Estimates of consumer welfare gains were generated by a series of simulations containing 18 parameters. The interaction of different assumptions of parameter values in the simulation model yielded a range of estimates. The median estimate for consumer welfare gains over five years was $2.2B for the linear scanning technology, and $1.5B for optical tape, using a 5% discount rate.

[287]Ibid., p. 12.
[288]Ibid., p. 23.

Table 8–4. Structured Interview Guide for Collecting Data Needed to Exercise the Model

TECHNOLOGY

- ✓ What are the most important technical innovations (attributes or characteristics) of your project?
- ✓ According to ATP documents, at the start of your project, your goals were to achieve *X, Y, Z* among the key characteristics. Can you confirm or update these capabilities.

  Optical tape: megabytes per second; terabyte capacity; meters/sec tape speed

  Digital linear scanning: megabytes per second; terabyte capacity; meters/sec tape speed
- ✓ At the start of your project, the best available technologies were capable of:
  - – Storage capacity: ***gigabytes.*** Your project was expected to archive XX MB/sec, a YY% improvement over the then-current BAT.
  - – Is this still correct? What is now the best currently available capacity?
  - – Data transfer rate: MB/s. Your project was expected to achieve XX MB/sec, a YY% improvement over the then-current BAT.
  - – Is this still correct? What is now the best currently available transfer rate?
- ✓ Has the pace of your own R&D achievements been as expected in these dimensions?
- ✓ Have R&D developments among your competitors been as expected?
- ✓ Have we failed to ask you about any important dimensions of your new product's performance? What units are they measured in, and what improvements do they promise with respect with BAT?

MARKET

- ✓ What is the innovation's primary market, or markets?
- ✓ What is the expected size of this market, in terms of units shipped?
- ✓ When do you expect to reach market?
- ✓ What is your expected adoption rate over 2–5 years (with uncertainty bounds)?
- ✓ At what price do you expect to sell the product embodying the new technology?
- ✓ How do you expect this price to trend over the first two years? Five years?

(continued on page 284)

Table 8–4. (Cont'd)

MARKET (CONT'D)

- ✓ What are your most important market-related hurdles?
  - Is it critical to be first to market?
  - How likely is it that improvements in the defender technology would render yours uncompetitive?
  - Does the success of your innovation depend on new applications arising for digital data storage?
  - Will it be necessary for users to adopt complementary technologies to take advantage of yours?
- ✓ What is the "off-the-shelf" price of the defender technology? [This item probes respondent's familiarity with or identification of its competitors. The model uses manufacturer data.]
- ✓ What rates of change in defender price and performance do you expect over the next two years, five years?
- ✓ Do you expect to compete on price with your innovation?
- ✓ What is the going market price for a unit of capacity (per MB), access time (per second), transfer rate (KB per second)? [This item sought innovator opinion on shadow values, especially for the latter two. The typical responses were sharply at odds with market data, with our hedonic analysis, and with opinions of disinterested experts.]
- ✓ Do you expect your innovation will drastically change any of these [shadow prices]?
- ✓ Have we omitted any important market issues?

Source: Austin and Macauley, *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage,* 2000, pp. 22–23.

Emerging Method: Using a Composite Performance Rating System Constructed from Case Study-Derived "Indicator" Data

A third emerging method sponsored by ATP, and developed by Rosalie Ruegg of TIA Consulting, Inc., is a composite performance rating system (CPRS). The CPRS, constructed from indicator metrics, is designed to provide an evaluation tool for the intermediate period after project completion and before longer term impacts can be measured. It scores each project in terms of 0 to 4 stars, depending on the strength of its overall progress toward knowledge creation and dissemination and commercialization. It provides a distribution of scores across the portfolio of completed projects.[289] Rooted in the descriptive case study method in combination with uniform compilation of indicator metrics, CPRS brings together a variety of mission-relevant information to provide a composite performance measure that is easy to grasp and communicate, and that can be used to characterize ATP's portfolio or projects. It was developed to meet a need not provided by existing evaluation methods.

An Additional Step in an Evolving, Multi-Step Framework

The development of CPRS is the most recent evolutionary step in ATP's use of descriptive case study methodology. As explained in Chapter 3, the descriptive case study method is among the simplest and best known of the evaluation methods. It is an evaluation mainstay for R&D programs because it lets the analyst tell the often-complex story of a scientific research project. A drawback is its focus on qualitative and anecdotal information that limits the method's usefulness as an evaluation tool.

A need had developed in ATP and its parent organization, National Institute of Standards and Technology (NIST), for an evaluation product that would provide a progress update for all ATP projects that takes into account the program's multiple goals.[290] As the first cases in the completed project status reports (described in Chapter 6) were being developed, an opportunity to extend the analysis became apparent. By specifying the data collection to cover a comprehensive set of output and outcome measures of progress toward achieving ATP's major goals, and collecting the data uniformly, it would be possible to construct aggregate statistics to describe a variety of output and outcome data for the portfolio of completed projects. These data were helpful, but too many to provide management a clear view of project and portfolio performance. The need by management and other stakeholders for a single measure of overall

[289]For a detailed description of the CPRS, see Ruegg, *A Composite Performance Rating System for ATP-Funded Completed Projects,* 2003.

[290]Performing in-depth economic assessments for all projects was considered impractical in terms of time and money.

performance provided the impetus behind development of the CPRS method described here. The purpose of CPRS is to consolidate the extensive amount of performance information from individual project case studies to produce a single symbolic performance rating which can be quickly grasped and used for comparisons and whose distribution across projects can be used to depict portfolio performance.

Construction of CPRS

Constructing a composite rating system that reflects the multiple dimensions of ATP's mission raises challenges about how to combine multiple metrics in a meaningful way. Despite inherent problems in clustering indicators and aggregating diverse data, there are numerous examples of rating systems in use that are based on multiple variables and multiple dimensions of interest. For example, the Quadrix Stock-Rating System uses more than 100 variables to score stocks in seven categories.[291] The approach of combining output/outcome data to indicate performance at different stages of the innovation process has precedence in the work of Eliezer Geisler. Geisler develops clusters of outputs for each stage of the innovation process, assigns normalized weights to each measure of each indicator, and calculates an overall index for each stage of outputs.[292]

General Formulation of CPRS

The CPRS is constructed as the sum of the weighted indicator measures for a set of mission-driven goals, adjusted to a 0–4 point scale. In its general form, CPRS is formulated as follows:

[291]The Quadrix Rating System was developed by Richard Moroney, editor of *Dow Theory Forecasts*.

[292]Eliezer Geisler, *The Metrics of Science and Technology* (Westport, CT: Quorum Books, 2000), pp. 243–266.

$$CPRS = \sum_{j=1}^{K} \sum_{i=1}^{N} (I_i \, \gamma_{Ij})_j \, A$$

where

I_i = the ith of N indicators of progress towards the jth of K mission-derived goals,

γ_{Ii} = the weighting factor applied to I_i indicator of progress,

N = the number of progress indicators for a given mission-derived goal, counting from i = 1 to N

K = the number of mission-derived goals for which there are progress indicators, counting from j = 1 to K

A = an adjustment factor for converting the total raw score to a 0–4 point scale.

Selecting Indicator Variables and Assigning Weights

The specification of the indicator variables and weights is *ad hoc* in nature because there is no general existing theory to guide their selection. The various indicator data that would be used to apply the method must reflect a program's specific mission statement and also take into account the feasibility of collecting the data. The weighting factors determine how the data are combined and, hence, how they contribute to the composite rating measure. Formulation of the weighting factors for ATP reflected the judgment of the analyst informed by the range of observed values of the selected variables for the first 50 projects, sensitivity testing, and guidance by senior ATP managers about desired characteristics for a rating tool. For application to a different program, the indicator metrics and weighting factors would need to be specific to that program.

The nine types of variables used to construct CPRS for ATP are listed in Chapter 6, Table 6–14. These are assigned weights and combined to calculate scores signaling progress of each project toward accomplishing each of three major goals of ATP: (1) knowledge creation, (2) knowledge dissemination, and (3) commercialization of the newly developed technologies. For example, the knowledge creation score is calculated from weighted values of technical award, patent filings, publications and presentations, and products and processes on the market or expected soon, while the commercialization progress score is calculated from weighted values of products and processes, capital attraction, change in company size, business awards, and outlook for future commercialization. Of the three goals, the second is assigned more potential weight than the first in computing the total raw score, and the third goal more than the second. This formulation is consistent with the premise that a project with sustained accomplishments by the innovator and their collaborators will continue to progress, eventually showing evidence of progress toward commercialization.

A factor is applied to the raw scores to facilitate assigning symbolic star ratings to each project. A score equal to or greater than 4 receives a four-star rating; a score less than 4 but greater or equal to 3, a three-star rating, and so forth.

Limitations of CPRS

This initial approach to constructing CPRS scores for ATP was exploratory. The CPRS as currently formulated represents an initial baseline, or prototype, system for trial use and further examination by ATP. From this baseline subsequent refinements can be made if desired.

Among the limitations to the approach is that the data for commercialization center mainly on the original innovator(s) and their collaborators, and are not indicators of commercialization by others outside the project. However, the seriousness of this limitation is alleviated by two factors. One is that efforts by others, if known, are reflected in the outlook data and, thus, not totally excluded. A second factor that alleviates this potential limitation is that the prototype CPRS is specifically designed to be applied within several years of project completion when early commercialization efforts typically still reside with the original innovators and their collaborators and licensees.

An additional limitation is that each CPRS score, like the case study information that underlies it, is time sensitive, and represents a snapshot, or benchmark, of performance at a particular time. Over time, the performance of individual projects may change, and performance measures may need to be updated. For example, the farther out in time from project completion one moves, the more important it becomes to investigate alternative commercialization paths stemming from knowledge spillovers, including paths revealed by patent citation analysis, and the more available are opportunities to include market measures of commercial impact in a composite score. Of course, as one moves farther out, opportunities to use benefit-cost and other evaluation approaches increase. The CPRS was developed specifically as an indicator-based evaluation tool to serve in the intermediate period, after project completion and before long-term benefits are realized.

More important limitations relate to data availability and methodology. The system is designed to use available data rather than ideal data. There is a lack of empirical verification of the relationships modeled. The construction of CPRS is necessarily *ad hoc* and improvisational, reflective of the absence of an underlying theory. There is precedence, however, for developing logic-based composite rating systems and for using expert judgment to assign weights to the selected indicator variables. As is the case with counterpart composite rating systems used by other Federal agencies, international bodies, hospitals, and businesses, the selection of indicator variables and the weighting algorithms specified in the CPRS are based on expert judgment constrained by the availability of data. Alternative algorithms may be superior.

In addition, the rating system is not expressed in terms of net benefits, and projects with the same "progress intensity" score may differ in their net benefits. In short, CPRS in its current state represents an initial prototype for trial use and further examination by ATP.

CPRS in Use

Current limitations notwithstanding, the CPRS method has practical utility to ATP's program managers and administrators. Implementation of CPRS has given ATP a new evaluation product rooted in case study, that gives stakeholders a quick take on project and portfolio performance. Because the method preserves the details of the case studies underlying the composite ratings, the results have a high level of transparency and the underlying data can be examined in detail.

Over time, there may be opportunities to improve formulation of CPRS. For example, patent citation data would likely be a better indicator of knowledge dissemination than patent counts. Regarding the construction of weighting factors, it might be possible to conduct supporting studies to inform the relationships between potential indicators and actual progress toward mission, for example, what should be the relative weights of publications, patents, and collaborative relationships in estimating their contribution to knowledge dissemination. At a minimum, more extensive sensitivity analysis could be conducted to determine how changing the baseline weights changes the results.

The general approach is extendable to other programs. But, other programs, with their different goals and output/outcome measures, would need a customized implementation of the general CPRS framework.

Summary of Other Evaluation Methods

This chapter has highlighted several additional traditional methods ATP has used for evaluation, together with three emerging methods whose development ATP supported. Evolving shifts in the demand for and supply of evaluation have shaped the choice of techniques. As the program has matured, new questions, typically of an increasingly nuanced or complex nature have arisen. Concurrently, the maturing of the program has generated increased quantities of data, especially longitudinal data, that make it possible to employ a wider set of standard methodologies and to experiment with newer ones.

In addition to the much used survey, case study, and econometric/statistical analysis methods, evaluators have applied two other traditional evaluation methods—expert judgment and bibliometrics—to the evaluation of ATP.

Expert judgment has been used to examine various facets of the program, ranging from underlying theory, to providing estimated input values for economic case studies, to the overall effectiveness of ATP. In 1999–2000, the NRC conducted an assessment of ATP's overall effectiveness using expert judgment as the central method, informed by studies carried out with a variety of other methods.

Bibliometrics, likewise a frequently used technique in science and technology program evaluation, has not been extensively used in ATP's evaluation program. Its use over most of ATP's first decade was limited to counts of publications and patents, with patent citation analysis being added late in the decade. The limited use early in the program is attributed largely to two factors: bibliometrics did not provide economic estimation at a time when stakeholders were pressing for economic performance metrics, and passage of time was needed to provide the databases required for more extensive citation analysis.

The support ATP provided to develop new evaluation methods reflected shortcomings in existing methods in the face of demanding evaluative requirements. One new method ATP supported is a cost index method for estimating social benefits, specifically market spillovers, from technological innovations. This method has been tested in applications to two digital storage technologies funded by ATP. The method is theoretically grounded and appears suitable for wider use both in ATP prospective case studies and those of other agencies.[293] Factors retarding wider use of the method are its large data requirements, large number of assumptions, complexity, and lack of transparency to managers.

Another of the new methods, CPRS, combines clusters of quantitative and qualitative indicator data gathered through descriptive case studies to rate overall project performance. A prototype CPRS has been implemented for ATP.

A third new method under development used fuzzy logic and social network analysis to improve the assessment of knowledge spillovers. With patent citations serving as a proxy for knowledge flows, the new method has been used to map research networks underlying two technical areas: MEMS and SWAT. With further development, the method offers a potentially important new way of identifying information needed to maximize knowledge spillovers and assess their magnitude.

Taken with the evaluation techniques reviewed in Chapters 4–7, Chapter 8 points to an extensive and increasingly sophisticated toolkit of methodologies available to evaluate ATP. For ATP evaluators, the challenge has been to select the most appropriate mix of tools for each analytical task. And, when a tool has not been invented to do that particular job, the challenge has been to design and create a new tool, adding to the body of knowledge about ATP and to the toolkit of all program evaluators.

[293] The cost index method has been applied to other agency programs, including NASA.