Abstract

Under its Intramural Program, the Advanced Technology Program (ATP) funds research and development (R&D) projects performed by the National Institute of Standards and Technology (NIST) scientists in the Measurement and Standards Laboratories (MSLs) for development of infrastructure technology in support of ATP's mission. This report presents the findings from a comprehensive evaluation of the effects of ATP's intramural funding during the period FY 1992 to FY 2000, providing both an assessment of the performance of the intramural program and a template for ongoing evaluation of performance.

To accomplish the evaluation, the report uses survey, benchmarking, and case study approaches. In a survey of NIST scientists who had received ATP funding, respondents described their ATP intramural projects and compared the outputs and outcomes of these ATP projects with hypothetical projects that would likely have been undertaken if ATP funding had not occurred.

Survey results, adjusted for response bias, found:

- ATP funding helps NIST laboratories initiate new research directions and thereby expand the scope of laboratory research.
- On average, two publications resulted from every three intramural projects, and each publication was cited in the literature about one and two-thirds times.
- On average, one presentation resulted from each project.
- More than 30 percent of reporting projects leveraged other sources of funding.
- Fifty-four percent of the projects would not have been undertaken in the absence of ATP support; the principal investigators believe that the remaining 46 percent would have taken longer to complete, been less technically challenging, and generated fewer technical outputs without ATP funding.

Detailed case studies of four selected projects that received intramural support illustrate industrially useful outputs and industrially productive outcomes; they show social rates of return on ATP's investments that range from 35 percent to 4,400 percent. Net present value for the selected projects ranged from $11 million to more than $8 billion (referenced to 2002 as the base year, in year 2000 dollars).

Acknowledgments

We are grateful to the Advanced Technology Program, especially to Jeanne Powell, for the opportunity to study in depth its intramural research program. Even with her support and encouragement, this study could not have been completed without the willing assistance of those NIST scientists who received ATP intramural support and who graciously gave their time to provide background information to us in the form of survey responses and—for our case studies—in the form of discussions with us in their laboratories. While many of these individuals and their projects are mentioned by name within the report, special thanks go to the following, without whose technical guidance this study would not have been completed. These individuals are (in the order in which their projects are discussed herein) Sarah Gilbert, Francis Wang, Thomas Rhodes, Barbara Goldstein, and Jan Obrzut. Many other respondents in industry generously gave us their time and expert observations, and we thank these industrial respondents here and—by company name—within the case studies. As well, many thoughtful comments and suggestions were received from those within ATP, and for these we are grateful. We thank Stephanie Shipp and Gary Anderson for their comments on an early draft of the report and Elissa Sobolewski, Brian Belanger (former ATP Deputy Director), and Barbara Cuthill for their comments on the final report.

Executive Summary

The Advanced Technology Program (ATP) within the National Institute of Standards and Technology (NIST) stimulates economic growth through the development of innovative technologies that are high in technical risk and enabling in the sense of having the potential to provide significant, broad-based economic benefits. The ATP statute permits the program to allocate up to 10 percent of its annual appropriations internally for standards development and technical activities in support of ATP's mission. This report presents findings from a comprehensive evaluation of ATP's intramural funding program during the period FY 1992 to FY 2000, when nearly $99 million was allocated to researchers within NIST's Measurement and Standards Laboratories.

The evaluation summarized in this report uses survey, benchmarking, and case study approaches.

Between FY 1992 and FY 2000, ATP funded 1,052 intramural projects. In the fall of 2001, each of the 278 principal investigators (PIs) still at NIST (who were involved in 510 of these projects) was surveyed electronically. Forty-three percent of these PIs responded to the survey. Based on a statistical analysis, principal investigators were more likely to respond when they had fewer ATP intramural projects, when those projects were more recent, and when the projects had larger budgets. These factors were used to adjust survey results for response bias.

The general framework for evaluating ATP's intramural research program builds on the general concepts that underlie the framework in which ATP evaluates itself, namely:

$$\text{inputs} \rightarrow \text{outputs} \rightarrow \text{outcomes} \rightarrow \text{impacts.}$$

Inputs include funding and research partnership formations; outputs include knowledge in general and inventions in particular; outcomes include acceleration of research and application of research results; and impacts include societal benefits.

Information collected during the survey phase of the study provided important background information about outputs and outcomes from funded projects, and it provided a comparison of funded projects with projects that would have been undertaken in the absence of ATP intramural funding. Specifically, the findings from the survey, appropriately adjusted to account for response bias, showed:

- ATP intramural funding can affect NIST's competencies by initiating new research directions within laboratories, thereby expanding the scope of the PI's laboratory research. This occurred in one of five projects.
- ATP intramural funding results in published research. On average, there were two publications per every three projects. Publications resulting from intramural projects could be benchmarked against all publications from all NIST laboratories. Statistically, ATP funded projects did not outperform other projects at NIST with respect to publications.
- As an indication of the importance of these publications, on average for every three publications there were about five citations by someone who was not involved in the project.
- On average, about one patent resulted from every 20 projects.
- On average, one extramural presentation was given per project.
- More than 30 percent of the funded projects leveraged other sources of research funding.
- In the absence of ATP funding, 54 percent of the projects would not have been undertaken. For two out of five of these cases where the PI said that projects with similar goals and milestones would *not* have been undertaken without ATP funding, an alternative project would have been undertaken in the same broadly defined research area. A majority of these hypothetical projects in the same broad research area would have generated less new measurement technology and fewer new standards than did the ATP project.
- In the absence of ATP funding, 46 percent of the projects would have been undertaken with similar goals and milestones. However, these hypothetical projects without ATP support, although with similar goals and milestones, would have:

    - taken an estimated twelve months longer to complete,
    - been less technically challenging, and
    - generated fewer technical outputs, including technical papers, new measurement technology, new standards, and new databases.

Four case studies were conducted, and for each case study metrics approximating the social rate of return of the funded research were calculated. The four research projects selected for case study were chosen in 2001 with input and advice from the three directors of ATP's technical offices. Three evaluation metrics are calculated for each case study: an internal rate of return, a benefit-to-cost ratio, and a net present value.

The four projects selected for case study are not necessarily representative of the population of ATP intramural projects. Those projects selected were believed to be among the relatively more successful projects in addressing the mission of the intramural funding program but were not necessarily the most successful. Thus, the case studies are illustrative of industrially useful outputs and industrially productive outcomes; generalizations from them to the population of ATP intramural projects would not typically be appropriate.

The four case studies are summarized below.

Wavelength References for Optical Fiber Communications: SRM 2517a

The goal of this project was to develop an improved standard reference material (SRM) for the measurement of the wavelength of light in an optical fiber network. In 1998, Dr. Sarah Gilbert in the Optical Fiber and Components Group of the Optoelectronic Division of the Electronics and Electrical Engineering Laboratory was awarded $145,000 over two years for this study of SRM 2517a, to replace SRM 2517. The new SRM benefited industry in the following ways. Its use by test equipment manufacturers brought about: production-related engineering and experimentation as well as calibration cost savings; increased production yields; negotiation (with customers over performance attributes) cost savings; and reduced marketing costs. This project was successful from an economic perspective as evidenced by an internal rate of return of 4,400 percent, a benefit-to-cost ratio of 267 to 1, and a net present value (referenced to 2002 as the base year, in year 2000 dollars) of $76 million.

Injectable Composite Bone Grafts

The goal of this project was to develop a new bone graft material superior to any product currently available for dental or orthopedic surgeries. In 1999, Dr. Francis Wang in the Polymers Division of the Material Science and Engineering Laboratory was awarded $409,000 over three years for this study. Dr. Wang developed calcium phosphate cement that was biocompatible with surrounding tissue and would regenerate new bone growth. Based on this research, manufacturers will be able to introduce by 2007 a new product that will: reduce the cost of dental implants, increase the success rate of periodontal surgeries, reduce recovery time from orthopedic surgeries, and allow orthopedic procedures on joints to become closed procedures. This project is expected to be successful from an economic perspective as evidenced by a prospectively calculated internal rate of return of 230 percent, a benefit-to-cost ratio of 5,400 to 1, and a net present value (referenced to 2002 as the base year, in year 2000 dollars) of over $8 billion.

Internet Commerce for Manufacturing

The goals of this project were to assist industries in developing open standards to enable the exchange of business and product data for all supply chain participants, to provide a flexible test bed for industry and government to collaborate in testing and evaluating standards-based tools and integration technologies, and to demonstrate business-to-business e-commerce. In 1996, Thomas Rhodes in the Software Diagnostics and Conformance Testing Division of the Information Technology Laboratory and Barbara Goldstein in the Electricity Division of the Electronics and Electrical Engineering Laboratory were awarded $580,000 over three years for this study. In November 2001, as a direct result of the research on this project, several Product Data eXchange (PDX) standards were adopted. The standards benefited original equipment manufacturers (OEMs) in the computer industry and contract manufacturers in the electronics manufacturing services (EMS) industry for the engineering and manufacturing of components to be used in printed circuit boards. Significant cost savings were realized by OEM and EMS companies as a result of improved data communications related to e-commerce. This project was successful from an economic perspective as evidenced by a prospectively calculated internal rate of return of 220 percent, a benefit-to-cost ratio of 33 to 1, and a net present value (referenced to 2002 as the base year, in year 2000 dollars) of over $23 million.

Polymer Composite Dielectrics for Integrated Thin-Film Capacitors

The goals of this project were to establish new metrology—test methods—to characterize electrical properties of embedded capacitance in printed circuit boards (PCBs) and to advance knowledge about the limits of this new system. In 1999, Dr. Jan Obrzut in the Polymers Division of the Materials Science and Engineering Laboratory was awarded $260,000 over three years for this study. Dielectric films can be used in the new packing solutions for the high performance chips combining resistors, capacitors, and microstrips with integrated circuits in PCBs. As a result, systems operate at higher frequencies and the PCBs are more functional. This technology is valuable to the PCB industry. Respondents reported that Dr. Obrzut's new test method will reduce the costs of characterizing materials, increase production yields, and enable industry to move forward into new products with higher frequencies, thus allowing for broader bandwidth communications technology. This project is expected to be successful from an economic perspective as evidenced by prospectively calculated lower-bound metrics showing an internal rate of return of 35 percent, a benefit-to-cost ratio of 7 to 1, and a net present value (referenced to 2002 as the base year, in year 2000 dollars) of about $11 million.

In summary, this first evaluation of ATP's intramural research program provided new information about the inputs, outputs, outcomes, and impacts of the program. Survey information from PIs confirmed that outputs and outcomes from their research projects could be collected and used to describe the impact of ATP funding on the PIs' research and their laboratories' research missions. The information also could be used to demonstrate knowledge spillovers that have resulted from the funded projects. From a broader perspective, the four case studies demonstrate clearly that there are significant economic benefits to industry associated with ATP's intramural funding. The case studies illustrate the types and magnitudes of benefits that industry is realizing because of the ATP intramural research program.

Contents

Figures

Appendix Figure

Tables

Appendix Tables

Background Information on ATP Projects Not Selected for Case Study

1 Introduction and Overview of the Study

Genesis of the Study

The Advanced Technology Program (ATP) within the National Institute of Standards and Technology (NIST) stimulates economic growth through the development of innovative technologies that are high in technical risk and enabling in the sense of having the potential to provide significant, broad-based economic benefits. Industry proposes research projects to ATP in fair, rigorous competitions in which proposed projects are selected for funding based upon both their technical and economic merits. Since its inception in 1990, ATP has announced 768 awards to single companies and joint ventures that involved more than 1,500 project participants. ATP has awarded approximately $2.3 billion and industry has provided approximately $2.1 billion in matching funds.

ATP's intramural program refers to research and development (R&D) projects performed by NIST scientists in the Measurement and Standards Laboratories (MSLs) and paid for with ATP appropriations. ATP's statute permits the program to allocate up to 10 percent of its annual appropriation internally for standards development and technical activities in support of ATP's mission. Since 1997, ATP has required that these intramural projects:

- emphasize generic basic research,
- relate to groups of ATP extramural projects (ATP's awards to industry for advanced technology development in furtherance of its fundamental mission), and
- focus on measurement and standards that would facilitate the deployment and diffusion of ATP-funded technologies developed in ATP's extramural projects.

The Economic Assessment Office (EAO) of ATP seeks to measure the economic impact of ATP's funding of high-risk, enabling technologies and also to increase understanding of economic relationships underlying technological change and economic growth. To this end, the EAO compiles data, conducts economic studies, and commissions studies by outside research organizations and economists.

This report presents findings from a comprehensive evaluation of ATP's intramural funding to the laboratories over the period FY 1992 to FY 2000.[1] It provides both a quantitative and a qualitative assessment of the internal impacts and spillover impacts of the knowledge base to industry associated with ATP's intramural funding. In a broader sense, the approach underlying this report could serve as a template for generation of performance measures and analysis of economic impacts of ATP's intramural research on an ongoing, routine basis.

ATP's Intramural Research Program

The ATP intramural research program provides funding to NIST laboratories to conduct research to advance the U.S. technology infrastructure in order to assist industry in continually improving products and services. Under the statute governing ATP, up to 10 percent of ATP's budget can be allocated for this research. As described below, the intramural program has stayed true to its mission but has changed in subtle ways.

ATP first made intramural research awards in fiscal year (FY) 1992; however, formal policies and procedures for intramural funds allocations were not finalized until December 1993. From 1993 through 1996, ATP's Executive Officer calculated a tentative amount to be allocated to each ATP technical office, and the directors of each technical office were responsible for allocating funds among the program managers within that office.[2]

During FY 1997, ATP's approach to intramural funding was revamped. Since 1997, the intramural funding has emphasized generic projects that cut across a group of ATP projects in order to provide the measurement and standards that facilitate the deployment and diffusion of ATP-developed technologies.

In 1998, ATP completed this transition. The emphasis of intramural research was broadened to take advantage of NIST's laboratory strengths and to build the research capabilities of the laboratories.

During the fiscal years 1992 through 2000, nearly $99 million was allocated toward intramural projects in the MSLs; see Figure 1. Funding ranged from $4.7 million in FY 1992 to almost $14 million in FY 2000. Only in 1992, 1993, and

2000 did the allocation for intramural funding come close to the allowable 10 percent allocation. The allocation for the remaining years ranged from a low of 3 percent in 1995 to 7 percent in 1998; see Table 1.

FIGURE 1. ALLOCATION OF INTRAMURAL RESEARCH FUNDS, BY FISCAL YEAR

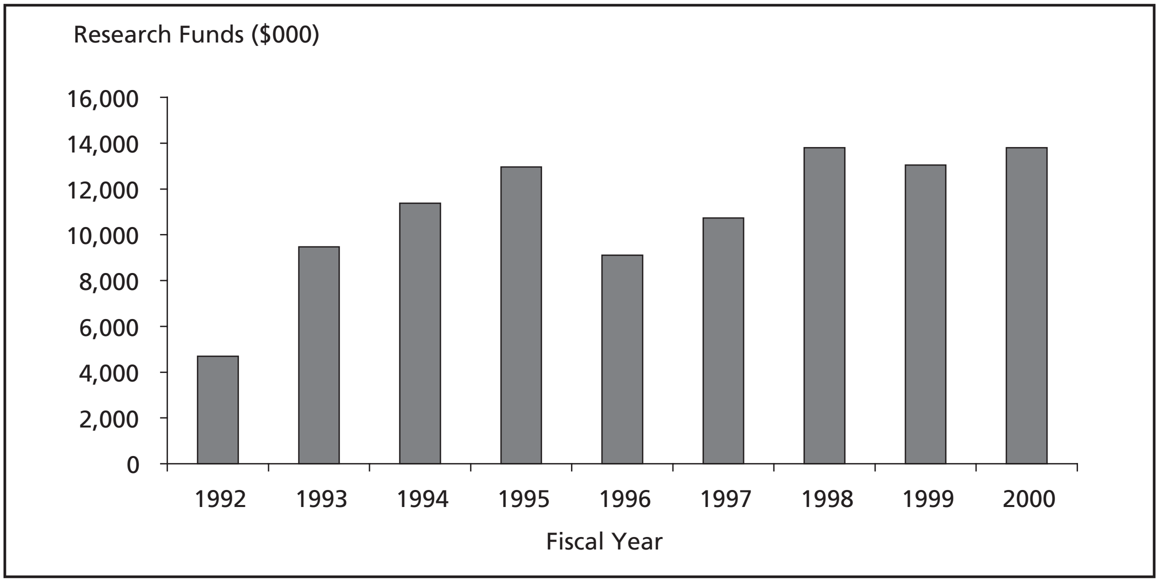


TABLE 1. INTRAMURAL RESEARCH FUNDING AS PERCENTAGE OF ATP ALLOCATIONS (ROUNDED %)

FY 1992	9.5
FY 1993	9.9
FY 1994	5.7
FY 1995	3.0
FY 1996	4.1
FY 1997	4.8
FY 1998	7.2
FY 1999	6.4
FY 2000	9.7

Note: The FY 1993 percentage does not include carry over funding from FY 1992. See notes to Table 2 below.

Laboratory Structure at NIST

The MSLs at NIST provide technical leadership for vital components of the nation's technology infrastructure needed by U.S. industry to continually improve its products and services. Currently, there are seven research laboratories at NIST:[3]

The *Electronics and Electrical Engineering Laboratory* (EEEL) promotes U.S. economic growth by providing measurement capability of high impact focused primarily on the critical needs of the U.S. electronics and electrical industries, and their customers and suppliers.

The *Manufacturing Engineering Laboratory* (MEL) performs research and development of measurements, standards, and infrastructure technology as related to manufacturing.

The *Chemical Science and Technology Laboratory* (CSTL) provides chemical measurement infrastructure to enhance U.S. industry's productivity and competitiveness; assure equity in trade; and improve public health, safety, and environmental quality.

The *Physics Laboratory* (PL) supports U.S. industry by providing measurement services and research for electronic, optical, and radiation technologies.

The *Materials Science and Engineering Laboratory* (MSEL) stimulates the more effective production and use of materials by working with materials suppliers and users to assure the development and implementation of the measurement and standards infrastructure for materials.

The *Building and Fire Research Laboratory* (BFRL) enhances the competitiveness of U.S. industry and public safety by developing performance prediction methods, measurement technologies, and technical advances needed to assure the life-cycle quality and economy of constructed facilities.

The *Information Technology Laboratory* (ITL) works with industry, research, and government organizations to develop and demonstrate tests, test methods, reference data, proof of concept implementations, and other infrastructural technologies.[4]

ALLOCATION OF INTRAMURAL RESEARCH FUNDS BY LABORATORY

Figure 2 shows the inter-laboratory distribution of these funds over the 1992 to 2000 time period. The Materials Science and Engineering Laboratory received the largest share (almost one-fourth of the funding) from 1992 to 2000. Three other laboratories, Electronics and Electrical Engineering, Manufacturing Engineering, and Chemical Science and Technology, each received about one-sixth of the funding over the nine years, and Information Technology received almost the same amount. The Physics and Building and Fire Research laboratories received the remaining funds.

FIGURE 2. ALLOCATION OF INTRAMURAL RESEARCH FUNDS, BY LABORATORY, 1992–2000

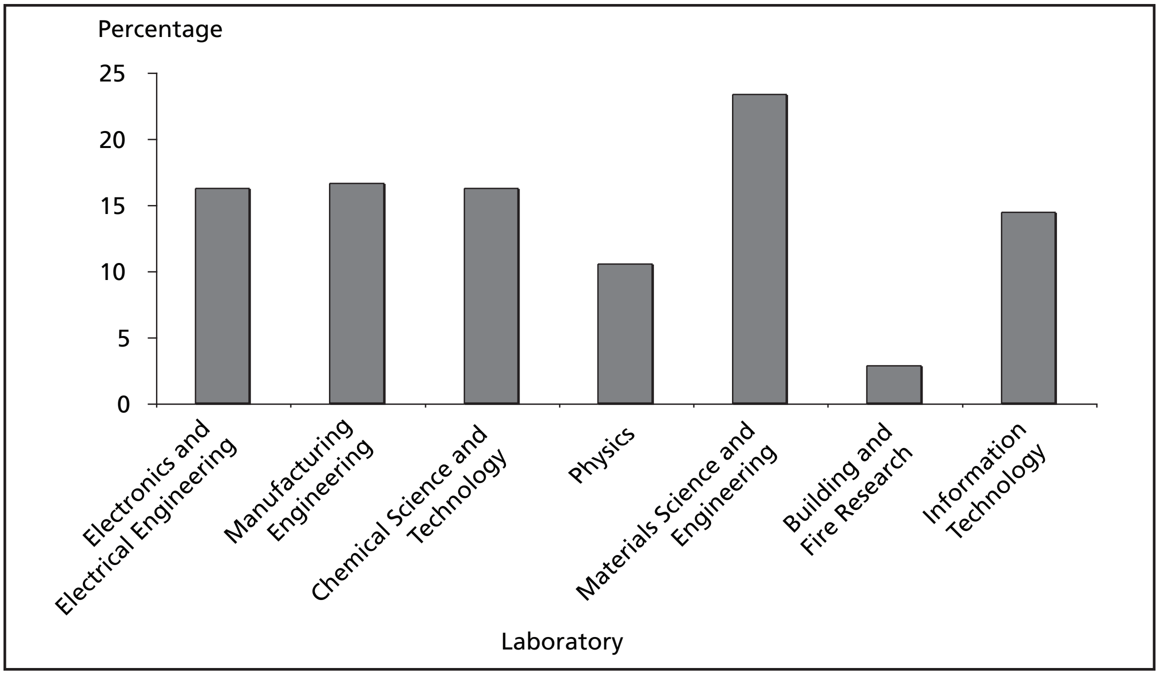


Table 2 shows both the total ATP funds allocated to intramural research as well as the distribution of those funds across each MSL, by fiscal year. Between 1992 and 2000, the relative distributions across MSLs show declines in the proportion of

TABLE 2. ALLOCATION OF INTRAMURAL RESEARCH FUNDS, BY LABORATORY AND BY YEAR (ROUNDED %)

Measurement and Standards Laboratory	Fiscal Year 1992	1993	1994	1995	1996	1997	1998	1999	2000
Electronics and Electrical Engineering (81)	20	24	26	17	12	11	14	15	11
Manufacturing Engineering (82)	23	19	17	17	18	17	17	14	13
Chemical Science and Technology (83)	10	12	15	9	12	18	20	21	22
Physics (84)	9	11	11	8	7	7	12	14	13
Materials Science and Engineering (85)	17	15	21	26	38	29	22	20	21
Building and Fire Research (86)	1	3	3	0.4	4	3	3	4	4
Information Technology (89)	19	16	6	23	9	16	13	12	17
Total ($1,000s rounded)	$4,700	$9,476	$11,373	$12,956	$9,104	$10,737	$13,804	$13,037	$13,796

Notes: Laboratory classification numbers are in parentheses. On February 16, 1997, NIST abolished the Computer Systems Laboratory (87) and the Computing and Applied Mathematics Laboratory (88) and combined the two to form the Information Technology Laboratory (89). Intramural allocations in fiscal years 1992 through 1996 to the former laboratories are shown in the table as allocations to the Information Technology Laboratory for purposes of comparisons. However, in the statistical analysis of the NIST scientist survey results, these laboratories are separated. When intramural funds were allocated to a project involving scientists from more than one MSL, all funds were allocated to the MSL of the first-named scientist. FY 1993 allocations include $2,754,000 of carry over FY 1992 funding.
Source: Fiscal year bulletins from ATP. ATP's fiscal year is October through September.

intramural funds going to the Electronics and Electrical Engineering and Manufacturing Engineering laboratories balanced by increases in the Chemical Science and Technology, Physics, Materials Science and Engineering, and Building and Fire Research laboratories. The dollar allocations in the last row of the table vary by year (see also Figure 1), but so has the overall ATP budget.

Table 3 shows the aggregated percentage allocations across MSLs in percentage terms. They provide the actual numerical values for the percentages conveyed visually in Figure 2.

TABLE 3. ALLOCATION OF INTRAMURAL RESEARCH FUNDS, BY LABORATORY (ROUNDED %), 1992–2000

Measurement and Standards Laboratory	Aggregated over All Years
Electronics and Electrical Engineering (81)	16
Manufacturing Engineering (82)	17
Chemical Science and Technology (83)	16
Physics (84)	11
Materials Science and Engineering (85)	24
Building and Fire Research (86)	3
Information Technology (89)	14
Total ($1,000s rounded)	$98,983

The fiscal year data in Table 2 and the aggregate data in Table 3 also show how intramural research funds have been allocated across MSLs in the context of the evolution of criteria for the selection of intramural research projects. In FY 1994 through FY 1998, ATP funding was applied to specific focused program areas—multi-year efforts aimed to achieve specific, well-defined technology and business goals. The increases in funding to the Materials Science and Engineering Laboratory in 1996 and to the Information Technology Laboratory in 1995 reflect the effect of focused programs. Beginning in FY 1999, all competitions returned to being open to all areas of technology, a feature that has long been the hallmark of general competitions.

FRAMEWORK FOR THE STUDY AND OVERVIEW OF THE FINDINGS

Our general framework for evaluating ATP's intramural research awards program builds on the framework in which ATP evaluates itself, namely:

inputs → outputs → outcomes → impacts.[5]

Within the context of the overall ATP program, inputs include funding and research partnership formation; outputs include knowledge in general and inventions in particular; outcomes include acceleration of research and commercial applications of research results; and impacts include societal benefits.

In the case of the intramural awards program, which supports internal projects that apply the research capabilities of NIST's laboratories to support ATP's mission, this general evaluation framework remains applicable.

The intramural research awards program enhances the activities of the NIST laboratories. In an ideal experiment, one would compare the outputs and outcomes associated with research within NIST laboratories *with* ATP intramural funding to the outputs and outcomes associated with comparable NIST laboratory research *without* ATP intramural funding. Another option would measure the outputs and outcomes associated with research in NIST laboratories over time and compare them between periods when ATP intramural funding was available and when it was not, all other things remaining constant. Neither evaluation approach is possible because comparable research projects could not be identified and because the relative newness of the intramural program made the time frame for a time-series study too short to accommodate research projects starting and being completed.

Thus, the best available approach encompassed several parts. NIST scientists who received ATP funding were asked to complete a survey that asked them to compare the outputs and outcomes from their research with hypothetically similar projects and broad NIST laboratory benchmarks. In addition, the output from the ATP-funded project was compared with the same type of output for all of the NIST laboratories' projects. Finally, because impacts (such as industrial impacts per the mission statement of the NIST laboratories) could not be documented from such a survey, detailed case studies of projects that received ATP intramural support were conducted. Such case studies are not intended to be representative of all funded projects, but rather to illustrate the breadth of societal benefits associated with ATP intramural funding.

Outline of the Remainder of the Report

The following section of the report summarizes the findings from the first part of the evaluation—a survey of all ATP intramural project principal investigators (PIs).

This survey was designed to collect information about project outputs relevant to an assessment of initial impacts associated with ATP's intramural funding.

The second part of the evaluation includes four case studies of ATP-funded projects. The methodology for selection of those studies is summarized, as are the metrics relevant for characterizing the spillover impacts to industry of the knowledge base developed in these projects. In addition, each case study is presented.

Appendices provide additional detail about the statistical analysis based on the PI survey and about the case studies.

Notes

1. This study is part of ATP's ongoing evaluation efforts. ATP received its first budget in 1990 and commissioned its initial evaluation guidelines in 1991. ATP's evaluation program has been expanded and improved over time.

2. See, "ATP Policy/Procedures for Intramural Funds Allocation," December 30, 1993.

3. In addition to these research laboratories, Technology Services provides a variety of products and services to U.S. industry such as Standard Reference Materials, Standard Reference Data, and Weights and Measures. Beginning in 2001, ATP provided some intramural funding to the Manufacturing Extension Partnership, NIST's program that provides technical and business assistance to smaller manufacturers.

4. The Computer Systems Laboratory (CSL) and the Computing and Applied Mathematics Laboratory (CAML) were combined on February 16, 1997 to form the Information Technology Laboratory. For purposes of inter-laboratory comparisons, pre-1997 information on these two MSLs is reported under the Information Technology Laboratory.

5. In their explanation of the evaluations of public R&D investments from ATP's perspective and experience, Ruegg and Feller (2003) discuss outputs and outcomes from a broad assessment perspective. Tassey (2003) also provides such perspective. These sources give examples of outputs: contributions to underlying science, developed generic technology or infrastructure technology, documented use in industry of generic technology or infrastructure technology, intellectual property, and the promulgation of industry standards. They also provide examples of outcomes: industry R&D investment decisions, market access and entry decisions, industry cycle time, productivity, market penetration of new technology, product quality, product and systems reliability, and reduced transaction costs. Further, they discuss and provide examples of the measurement of the social benefits—the impacts.

2 Quantitative Analysis of the Effects of ATP Intramural Funding

Methodology for Data Collection

In the fall of 2001, with input from the ATP, we designed a survey instrument for all ATP intramural project principal investigators. It was pre-tested and sent electronically to the 278 project PIs at NIST at the time.[1,2] During FY 1992 through FY 2000, ATP funded 1,052 intramural projects. The 278 surveyed PIs were associated with 510 of these projects.

An introductory letter from ATP's Deputy Director informed Operating Unit Directors that the results of this survey are intended to help ATP know how to collaborate better with the laboratories using intramural funding. In addition, ATP expects statistics from the survey to be useful in summarizing some of the laboratories' achievements as a result of the funding.

In early December 2001, each PI who did not respond to the first survey was sent a reminder email. No surveys were received after the end of 2001.

A total of 209 surveys were returned with at least some information for one or more projects. This represents a response by 43 percent of the 278 PIs; the surveys included at least some information for 41 percent of the 510 projects;[3] 30 reported that no information was available on the project because of its age.

Response rates differed for each question. Generally, a PI was *less likely* to respond to a question for a particular project the greater the number of intramural research awards that the PI received, and the greater the age of the project. In contrast, response was *more likely* the larger the budget of the project.

These three response-determining factors appear intuitive. The more projects for which a PI was asked information, the greater the total time burden to the PI and the less likely he or she would respond. Similarly, greater time would be needed by the PI to retrieve requested information about an older project. PIs with larger budgets perhaps responded more often because the breadth and scope of the research was greater; hence its importance to the PI's research agenda was greater. Statistical adjustments were made for non-response bias.

FINDINGS FROM THE SURVEY DATA

The survey information collected relates to:

- project outputs and outcomes, and
- comparisons with projects that would have been undertaken in the absence of ATP intramural funding.

Scope of project, publications, and presentations are an integral part of the research mission of NIST scientists and are used as measures of project outputs. Patents are not an integral part of NIST's intramural program mission, yet some early projects produced patents. The results from the NIST PI survey suggest the following project outputs. They are summarized here because of the statistical complexity of the analysis, but are presented in full detail in Appendix B.[4] Below and throughout this section of the report, the survey findings reflect adjustments for response bias. We found:

- ATP funding potentially enhances NIST competencies by initiating a new research direction and thereby expanding the scope of the PI's laboratory research, or by complementing the PI's ongoing research agenda. On average, PIs perceive the scope of laboratory research was expanded in one of five projects.
- Less than one publication resulted from each intramural project (there were on average two publications for every three projects), and each publication was cited in the literature by someone who was not involved in the project about one and two-thirds times (there were on average about five citations for every three publications).[5]
- On average, one patent results from about every 20 projects among the reporting projects.
- On average, one presentation results from each project.
- Over 30 percent of the reporting ATP intramural projects leveraged other sources of funding such as NIST competency awards or Cooperative Research and Development Agreement (CRADA) activity.

The quantities of publications, patents, and so forth describe absolute measures of output performance, but do the numbers reflect good performance? That is, relative to NIST projects in general, do the ATP-funded NIST projects perform well? We were able to provide one actual comparison, and for multiple measures of performance we were able to collect and analyze the PIs' assessments of the performance differences between ATP intramural projects and hypothetical, similar projects in the NIST laboratories that would not have ATP support.

Comprehensive NIST benchmark data were available only for one output measure—publications per million dollars of budget. Actual publication performance for the reporting ATP intramural projects outperformed publication performance from a typical NIST project as revealed in the benchmark data. However, projects for which survey responses were obtained appear to have more publications than the typical ATP intramural project, so the average publication performance for ATP funded NIST projects may be no different from the typical NIST research project.

In addition to the above analysis of the quantitative outputs and outcomes associated with intramural projects, qualitative information was collected in an effort to compare the nature of the intramural funded project with that of research activity that would have occurred in the absence of such funding. PIs reported that:

- In the absence of ATP funding, 54 percent of the projects would not have been undertaken. For two out of five of these cases where the PI said that projects with similar goals and milestones would *not* have been undertaken without ATP funding, an alternative project would have been undertaken in the same broadly defined research area. A majority of these hypothetical projects in the same broad research area would have generated less new measurement technology and fewer new standards than did the ATP project.
- In the absence of ATP funding, 46 percent of the projects would have been undertaken with similar goals and milestones. However, these hypothetical projects without ATP support, although with similar goals and milestones, would have:

  - taken an estimated twelve months longer to complete,
  - been less technically challenging, and
  - generated fewer technical outputs, including technical papers, new measurement technology, new standards, and new databases.

In sum, in more than half the cases, similar projects would not have been undertaken in the absence of ATP support, and for the remaining 46 percent of projects where NIST would have had similar projects, the ATP-supported projects are perceived by the PIs to have outperformed the analogous projects that would have taken place without the ATP support.

NOTES

1. The survey instrument is in Appendix A.

2. The principal investigator for an intramural project was identified to be that individual listed on the ATP intramural project budget allocation records at the time the award was made. If a project was awarded to more than one researcher, it was assumed that the first named researcher was the PI.

3. The survey contains several open-ended questions, but very few PIs responded to them and thus no discussion of those sparse responses is presented herein.

4. The word "suggest" is used because actual survey responses are adjusted for the response effect when that effect was statistically significant.

5. *A priori*, pre-1997 projects might have different publication rates, other things being the same, because in 1997 the focus of the intramural awards program changed from supporting specific external projects to supporting more broad-based projects. As noted in Appendix B, the pre-1997 respondents reported somewhat more publications per project than the respondents for later years. However, once the complete model with response effects is estimated, the publication rates for the pre-1997 period and the subsequent years are essentially the same.

3 Case Study Selection and Methodology

Four detailed case studies were conducted as part of our evaluation of ATP's intramural research program.

Selection Process

During an initial December 2000 meeting with the directors of the three technical offices within ATP—chemistry and life sciences (CLSO), electronics and photonics technology (EPTO), and information technology (ITO)—each director was asked to identify four or five intramural research projects for possible case study.[1] Two criteria were offered to the directors to guide their initial selection process:

- the ATP intramural project must have documentable technical outputs and industrial applications, and
- the intramural project's principal investigator (PI) must currently be employed at NIST.

During a second meeting with the directors and selected intramural ATP project mangers (PMs) in February 2001, sixteen candidate projects were recommended. As shown in Table 4, four projects were suggested from CLSO, seven from EPTO, and five from ITO. After this second meeting, in-person and/or telephone interviews were held with the identified PMs.

Twelve of sixteen PIs associated with the projects listed in Table 4 were interviewed face-to-face at NIST-Gaithersburg; three PIs were at NIST-Boulder and were interviewed by telephone; the sixteenth PI is at NIST-Gaithersburg, but he declined to be interviewed or to participate in the study. Based on these interviews, we reduced the population of candidate projects from sixteen to nine. This was a subjective reduction, taking into account whether there actually were at that time documentable technical outputs and outcomes with socially valuable industrial applications and taking into account the willingness of the PI to participate in a follow-up case study.[2]

The nine projects selected for consideration for detailed case studies are shaded in Table 4 and summarized in more detail in Table 5. In April 2002, this group of nine was presented for discussion purposes to ATP along with our recommendations for four detailed case studies. Our recommendations were based in part on having talked with individuals in industry, who had been identified by the PI, about measurable benefits and the likelihood of identifying others with whom we could talk,

TABLE 4. INITIAL CANDIDATE INTRAMURAL RESEARCH PROJECTS FOR CASE STUDY

Technical Office	Project Title	Funding History
CLSO	Injectable Composite Bone Grafts: Biocompatability and Comparability	FY 1999–2001
CLSO	Infrastructure for Development of Selective Membrane Platforms	FY 1998–2000
CLSO	Microstructure Characterization by Nondestructive Imaging for Permeability Prediction and Failure Mechanism Evaluation	FY 1998–2000
CLSO	Fatigue Resistance of High Performance Polymeric Composite Immersed in Sea Water	FY 1998–2000
EPTO	Wavelength References for Optical Fiber Communications	FY 1998–1999
EPTO	A Novel Method for Fabricating Critical Dimension Reference Materials with 100 nm Linewidths	FY 1999–2000
EPTO	Compound Semiconductor Composition Standards	FY 1998–2000
EPTO	Polymer Composite Dielectrics for Integrated Thin-Film Capacitors	FY 1999–2001
EPTO	Optimal Design of NIST Microactuators for Precision Machines (and follow on work under the title Deformable Structure Micro Positioners)	FY 1998–2001
EPTO	In-Situ Measurement of Temperature for Semiconductor and Thin-Film Processing	FY 1997–1998
EPTO	Interconnect, Probe/Test Fixture, and Material Characterization Using Advanced Time Domain Measurements	FY 1999–2001
ITO	NIST WebMetrics Project	FY 1998
ITO	Development of Methodology and Function Security Architecture for Construction of ISO/IEC 15408 Security Protection Profiles for Healthcare Information Systems	FY 1999–2001
ITO	Fundamental Studies of Dislocation Structures During Deformation	FY 1998–2000
ITO	Machine Tool Characterization Monitoring and Control	FY 1996–1998
ITO	Internet Commerce for Manufacturing	FY 1998–2000

TABLE 5. SUB-SAMPLE OF NINE CANDIDATE INTRAMURAL RESEARCH PROJECTS FOR CASE STUDY

Technical Office	Project Title	PI	PI's Laboratory	Project's Output
CLSO	Injectable Composite Bone Grafts: Biocompatability and Comparability	Wang	MSEL	Product
EPTO	Wavelength References for Optical Fiber Communications	Gilbert	EEEL	Standard Reference Material
EPTO	Polymer Composite Dielectrics for Integrated Thin-Film Capacitors	Obrzut	MSEL	Test Method
ITO	Internet Commerce for Manufacturing	Rhodes et al.	ITL, MEL, EEEL	Standard
EPTO	Optimal Design of NIST Microactuators for Precision Machines (and follow on work under the title Deformable Structure Micro Positioners)	Dagalakis	MEL	Product, Test and Calibration Methods
ITO	NIST WebMetrics Project	Laskowski	ITL	Tool
ITO	Development of Methodology and Function Security Architecture for Construction of ISO/IEC 15408 Security Protection Profiles for Healthcare Information Systems	Johnson	ITL	Standard
ITO	Fundamental Studies of Dislocation Structures During Deformation	Fields	MSEL	Product
ITO	Machine Tool Characterization Monitoring and Control	Donmez	MEL	Standard

Notes:
MSEL—Materials Science and Engineering Laboratory
EEEL—Electronics and Electrical Engineering Laboratory
MEL—Manufacturing Engineering Laboratory
ITL—Information Technology Laboratory

and in part on having a cross-technical office and a cross-NIST laboratory representation. The justification for our recommendations was discussed among the ATP staff at the meeting before our recommended four projects were chosen as the ones for the more detailed case studies.

The four projects selected for case studies (shaded in Table 5) are not representative of the population of ATP intramural projects, or of projects for which the PI was still at NIST, or of projects with identifiable outputs. Our selection of the four projects was based on the objective and subjective criteria described above, and the evaluation findings from the four case studies in this report should be interpreted in that light. Those selected were believed to be among the more successful (but not necessarily the most successful) projects in addressing the intramural program mission based on the screening process. Generalizations of quantitative outcomes and impacts to the population of ATP intramural projects would not be appropriate.

More details about each of the four projects selected are in the background information in each of the case studies that follow. Details about the five projects not selected for case study are in Appendix C.

Systematic Evaluation Methodology and Metrics

Fundamental to an evaluation of any federal program, for research or otherwise, is that the program is accountable to the public. For research programs, such accountability refers to being able to document and evaluate research performance using metrics that are meaningful to the institutions' stakeholders—the public, including the taxpayers.[3] Metrics developed for assessing returns to private investment have been adapted to public investments using case study techniques that emphasize analysis of public benefits to research users and taxpayers.

With any performance evaluation, it is generally assumed that the government has an economically justifiable role in supporting innovation because of market failures stemming from, among other things, the private sector's inability to appropriate returns to investments, the public-good nature of the research focus, or the riskiness of those investments.[4] Ignoring such an assumption may imply that any evaluation of a public research program is wanting in the sense that the program has not been scrutinized initially on first principles as to why it is even undertaking research.

Griliches (1958) and Mansfield et al. (1977) pioneered the application of fundamental economic insight to the development of measurements of private and social rates of return to innovative investments. Streams of investment costs generate streams of economic benefits over time. Once identified and measured, these streams of costs and benefits are used to calculate such performance metrics as social rates of return and benefit-to-cost ratios.

For example, for a process innovation adopted in a competitive market, using the traditional framework, the publicly funded innovation being evaluated is thought to lower the cost of producing a product to be sold in a competitive market. As the innovation lowers the unit cost of production, consumers will actually pay less for the product than they paid before the innovation and less than they would have been willing to pay—a gain in consumer surplus. The social benefits from the innovation include the total savings that all consumers and producers receive as a result of producers having adopted the cost-reducing innovation. Depending on the extent to which reduced costs are reflected in the price charged to consumers, social benefits are shared by producers who adopt the innovation and consumers of their products. Thus, the evaluation question that can be answered from this traditional approach is: Given the investment costs and the social benefits, what is the social rate of return to the innovation?

The traditional evaluation method pioneered by Griliches and Mansfield is used in this study.[5] To implement that method, two general data series are needed. One data series is related to investment costs, and in the case of this study the relevant investment costs are those associated with the ATP intramural project.[6] The other data series is related to the benefits realized by society, net of pull costs. These are costs to industry, over and above any fees paid to NIST for the infrastructure technology in question, to be able to assimilate and use the technology—i.e., to "pull in" the technology and make it useful in the particular industrial application. Society includes both private sector companies and consumers. ATP's investment costs are known. Benefit data have to be collected, and these data can be of two types. Benefit data can be retrospective in nature, meaning that the company or consumer who has benefited from the ATP project has already realized benefits; or benefit data can be prospective in nature, meaning that the company or consumer who will benefit in the future from the ATP project can estimate when and to what degree benefits will be realized.[7] Both types of benefit data were collected in this study.

Quantifying Social Rate of Return Metrics

Using the time series for costs and benefits measured in constant dollars, the internal rate of return, the benefit-to-cost ratio, and the net present value for the project are calculated in each of the four case studies using the year when each project began as the base year. In addition to those three customary metrics, net present value referenced to year 2002 was also computed for each case study for comparative purposes.

The metrics are calculated from the time series of costs and benefits in year 2000 dollars. Costs and benefits were converted to constant dollars to allow all dollar figures to be directly comparable. All dollar figures have been converted to year 2000 dollars using the chain-type price index for gross domestic product provided in the *Economic Report of the President*.[8] Year 2000 was chosen because, at the time that the case studies were conducted, that was the most recent year for which complete annual data were available.

Internal Rate of Return[9]

The internal rate of return (IRR) is the value of the discount rate, i, that equates the net present value (NPV) of the stream of net benefits associated with a research project to zero.[10] The time series runs from the beginning of the research project, $t = 0$, to a terminal point, $t = n$.

Mathematically,

(1)
$$\text{NPV} = \left[(B_0 - C_0)/(1+i)^0\right] + \ldots + \left[(B_n - C_n)/(1+i)^n\right] = 0$$

where $(B_t - C_t)$ represents the net benefits associated with the project in year t, and n represents the number of time periods—years in the case studies evaluated in this report—being considered in the evaluation.

For unique solutions for i, from equation (1), the IRR can be compared to a value, r, that represents the opportunity cost of funds invested by the technology-based public institution. Thus, if the opportunity cost of funds is less than the internal rate of return, the project was worthwhile from an *ex post* social perspective.

Benefit-to-Cost Ratio

The ratio of benefits-to-costs (B/C) is the ratio of the present value of all measured benefits to the present value of all measured costs. Both benefits and costs are referenced to the initial time period, $t = 0$, when the project began as:

(2)
$$\text{B/C} = \left[\sum_{\text{t=0 to t=n}} B_t/(1+r)^t\right] \Big/ \left[\sum_{\text{t=0 to t=n}} C_t/(1+r)^t\right]$$

A benefit-to-cost ratio of 1 is said to indicate a project that breaks even. Any project with B/C > 1 is a relatively successful project as defined in terms of benefits exceeding costs.

Fundamental to implementing the ratio of benefits-to-costs is a value for the discount rate, r. While the discount rate representing the opportunity cost for public funds could differ across a portfolio of public investments, the calculated metrics in this report follow the guidelines set forth by the Office of Management and Budget in Circular A-94 (1992), which states that: "Constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent."

Net Present Value

The information developed to determine the benefit-to-cost ratio can be used to determine net present value (NPV) as:

(3) $$\text{NPV}_{\text{initial year}} = B - C$$

where, as in the calculation of B/C, B refers to the present value of all measured benefits and C refers to the present value of all measured costs and where present value refers to the initial year or time period in which the project began, $t = 0$ in terms of the B/C formula in equation (2). Note that NPV allows, in principle, one means of ranking several projects *ex post*, providing investment sizes are similar.

To compare the net present values across the four case studies with different starting dates, the net present value for each is brought forward to year 2002, making 2002 the base year. The $\text{NPV}_{\text{initial year}}$ is brought forward under the assumption that the NPV for the project was invested at the 7 percent real rate of return that is recommended by the Office of Management and Budget as the opportunity cost of government funds. NPV_{2002} is then a project's NPV multiplied by 1.07 raised to the power of 2002 minus the year that the project was initiated as:

(4) $$\text{NPV}_{2002} = \text{NPV} \times (1.07)^{2002 \text{ - initial year}}$$

Notes

1. The three technical offices have subsequently been reorganized into two: the Chemistry and Life Sciences Office (CLSO) and the Information Technology & Electronics Office (ITEO).

2. While documentable technical outputs with socially valuable industrial applications were criteria upon which the ATP project managers were to recommend projects, in some instances the PM was not sufficiently familiar with the outcomes and impacts of the project after ATP funding ended to make a judgment as informed as we could make after our detailed interviews.

3. The Government Performance and Results Act of 1993 (GPRA) required that public institutions' research programs identify outputs and quantify the economic benefits of the outcomes associated with such outputs. Some public agencies have skirted the issue by arguing that the research they do or that they fund is peer reviewed, and thus it is sound; and if the research is sound, it must be socially valuable. Many embrace the importance of having research peer reviewed both at the pre-funding stage as well as upon completion. However, the peer review process certainly does not address in any precise or reliable way whether or not the research is socially valuable from an economic standpoint. It is not so much that a formal analysis of social economic rates of return is officially out of bounds for the peer review process; rather, such an analysis is simply not a part of the peer review process as it currently exists. Other public agencies are attempting to be more exact in their approach to meeting the GPRA requirement to quantify outcomes' benefits. However, the hurdle that is difficult for most public agencies to clear is how to quantify benefits in a methodologically sound and defensible way.

4. The origin of this assumption can be traced at least to Vannevar Bush (1945), although Link and Scott (1998, 2001) have placed this assumption in a specific policy context.

5. Link and Scott have developed, through ongoing evaluations of federal research programs, an alternative approach to the economic evaluation of publicly funded research. This approach differs from traditional evaluation methods that have been used. The alternative approach is needed to provide additional insights because the traditional evaluation methods are limited in a Government Performance and Results Act (GPRA) world that is performance accountable. The genesis of this approach is in Link (1996a), and recent applications are in Link (1996b) and Link and Scott (1998, 2001). Link and Scott, and others, have used this approach in a number of the evaluation studies sponsored by the Program Office at NIST, as well as in several ATP-sponsored projects.

6. As relevant, other investment costs will be discussed in the case studies. Such investment costs are costs that the private sector will incur to utilize the ATP project's output. These are, stated differently, the costs incurred by the private sector to pull in ATP's output and utilize it efficiently. Hence, these costs are referred to as pull costs.

7. Of course, it is assumed that the benefit information provided by interviewed individuals is accurate and reproducible should subsequent interviews by others take place.

8. See CEA (2002), Table B-7, "Chain-type price indexes for gross domestic product, 1959-2001." The index number for 2001 was estimated as the average of the three quarterly observations available.

9. The characterization of the three metrics follows Link and Scott (1998).

10. Using the constant dollar figures for costs and benefits, the internal rate of return is a "real" rate of return. In contrast, some economic impact assessments (including many conducted for NIST's Program Office) have presented "nominal" rates of return that were based on time series of current dollars (the dollars of the year in which the benefits were realized or the costs were incurred).

4 CASE STUDY OF Wavelength References for Optical Fiber Communications: SRM 2517a

Goals of the Project

The goal of this project was to develop an improved standard reference material (SRM) for the measurement of the wavelength of light in an optical fiber network.

Background Information and Overview of the Project

The Optoelectronics Division of the Electronics and Electrical Engineering Laboratory began research on optical communications in the mid-1970s and expanded its research program substantially in the late 1980s. The Optical Fiber and Components Group of the Division began research on SRMs in 1991. The Group's first SRM became available in 1993 with SRM 2520, an optical fiber diameter standard. Since then the Group has produced a number of optoelectronic standards. SRM 2517 was issued in 1997; it was intended for use in calibrating the wavelength scale of wavelength measuring equipment in the spectral region from 1510 nm to 1541 nm.

In 1998, Dr. Sarah Gilbert in the Optical Fiber and Components Group began a two-year ATP intramural project to develop a more accurate version of SRM 2517. Dr. Gilbert received $145,000 over two years—$70,000 in fiscal year 1998 and $75,000 in fiscal year 1999.

The project produced the new SRM for calibration of wavelengths in the spectral region from 1510 nm to 1540 nm. The references in the 1500 nm region are important to support wavelength division multiplexed (WDM) optical fiber communications systems. In a WDM system, many channels, each associated with a different wavelength, of communication information are sent down the same fiber. Thus, wavelength division multiplexing in effect increases the bandwidth of the communications system, because any given spectral region will support more channels through which communications information can be sent. A WDM system requires stable wavelengths throughout the components of the system, and equipment must be calibrated to measure those wavelengths. The wavelength references provided by NIST are needed to calibrate the instruments—such as optical spectrum analyzers, tunable lasers, and wavelength meters—that are used to characterize the components of WDM optical fiber communications systems. The wavelength references are also used to monitor the wavelengths of the channels while the system is in use, because if one channel's wavelength were to shift, crosstalk could occur between it and a neighboring channel, thus disrupting the accurate flow of communications information through the channels of the system.

The output of Dr. Gilbert's ATP-funded NIST research with William Swann was Standard Reference Material 2517a, High Resolution Wavelength Calibration Reference for 1510 nm—1540 nm Acetylene ($^{12}C_2H_2$). Quoting NIST's description of the new SRM provides an exact description of the artifact—an "absorption cell" filled with acetylene gas that produces characteristic "absorption lines" in the readouts resulting when lasers project light of various wavelengths through the gas-filled cell. The absorption lines observed can then be used to identify the wavelengths for the laser-emitting device being calibrated.[1] NIST's description of the artifact is as follows.[2]

> Standard Reference Material 2517a is intended for wavelength calibration in the spectral region from 1510 nm to 1540 nm. It is a single-mode optical-fiber-coupled absorption cell containing acetylene ($^{12}C_2H_2$) gas at a pressure of 6.7 kPa (50 Torr). The absorption path length is 5 cm and the absorption lines are about 7 pm wide. The cell is packaged in a small instrument box (approximately 24 cm long × 12.5 cm wide × 9 cm high) with two FC/PC fiber connectors for the input and output of a user-supplied light source. Acetylene has more than 50 accurately measured absorption lines in the 1500 nm wavelength region. This SRM can be used for high resolution applications, such as calibrating a narrow-band tunable laser, or lower resolution applications, such as calibrating an optical spectrum analyzer.

The main difference between the new wavelength calibration standard, SRM 2517a, and its predecessor, SRM 2517, is the use of lower pressure in the acetylene cell to produce narrower lines. Because of that difference, SRM 2517a can be used in higher resolution and higher accuracy applications.

Implications for Industry and Society

This ATP intramural project complemented the SRM-related research of the Optical Fiber and Components Group and was a natural extension of previous research related to SRM 2517.[3] While research on SRM 2517a would have occurred in the absence of ATP's support, it would not have progressed as rapidly. According to Dr. Gilbert: "The ATP funding accelerated this project and enabled us to complete the development of a new wavelength calibration SRM about one year faster than we would have without this funding."

Thus, if ATP had not funded the project, the NIST laboratory would have invested a similar amount, but the streams of benefits and costs would have been roughly a year later. In this case study, we evaluate the social rate of return for the project. We do not try to identify the incremental gain from having the project funded by ATP rather than the NIST laboratory that performed the research.

NIST has been selling SRM 2517a at a rate of two to three per month since it was introduced in late 2000. The rough breakdown of all of the SRM 2517a sales by industry category is 45 percent to manufacturers of test equipment, 30 percent to manufacturers of components, 10 percent to companies providing network systems, and 15 percent to other users—mostly research laboratories—of the SRM. According to Dr. Gilbert, a company will typically purchase one SRM 2517a.

Benefit and Cost Information[4]

Detailed descriptions of the uses of SRM 2517a are provided below, but NIST's experience suggests that most of the test equipment manufacturers in industry use the SRM units to conduct periodic calibration checks on their equipment. The calibration checks with the SRM are not typically in the production line where various intermediate standards are used for routine calibration checks. Rather, the SRM is used to check those intermediate standards. Some of these test equipment manufacturers make absorption cells—commercial versions of the SRM 2517a artifact described above—to incorporate into their products. In those situations where the absorption cells are purchased, discussions with industry experts reveal that SRM 2517a is used both to check the commercial versions of the absorption cells and for study as a manufacturing guide in the production of the commercial high-volume versions of the cell. Discussions with industry show that the component manufacturers often integrate the SRM 2517a into their production lines to continuously calibrate their equipment. Network systems providers use the SRMs to calibrate their test equipment.

The industry costs and benefits for SRM 2517a are based on estimates—obtained through detailed telephone interviews—from industry respondents that collectively have purchased about 30 percent of the SRM 2517a cells.[5]

Discussions with industry identified several types of benefits and costs associated with SRM 2517a. Benefits fall within five general categories: production-related engineering experimentation cost savings, calibration cost savings, yield, negotiation, and marketing. Costs are the ATP development costs plus the pull costs associated with using the SRM purchased from NIST.

Separating the SRM 2517a benefits from the benefits of other SRMs in the 25xx family was often difficult for industry respondents.[6] Some use the entire set of SRM 25xx artifacts; those respondents sometimes think of the set of artifacts as an integrated whole, covering different parts of the spectrum of wavelengths to which equipment must be calibrated. Thus, to some extent the benefit estimates below reflect a joint benefit from the set of NIST SRM 25xx artifacts. However, there are also major sources of unmeasured industrial benefits from SRM 2517a. As a result, the benefit estimates used are, on balance, conservative for at least three reasons. First, the estimates are truncated after ten future years, even though some respondents believed that the commercial usefulness of SRM 2517a would extend well beyond that period. Second, and more important, many respondents could not quantify the loss in sales, and therefore profits, that would occur without traceability to NIST of their wavelength calibrations. And third, the benefit estimates reflect only the benefits to the purchasers of the NIST SRM 2517a artifacts; they do not capture the additional benefits to users further down the supply chain. As one respondent whose company manufactures commercial gas cells (based on SRM 2517a) for use in instruments stated: "If there were no SRM 2517a, all along the way through the supply chain additional calibration expenses (suites of equipment and extra labor costs) would be incurred. Roughly half of the optical spectrum analyzers sold to industry incorporate the SRM 2517a technology to calibrate better. There would be extra expense and time at each research site." Given these sources of downward bias, we believe that, on balance, the benefit estimates used to compute the evaluation metrics to characterize the outcomes of SRM 2517a are conservative.

Use of SRM 2517a results in:

- **Production-related engineering and experimentation cost savings**

Users of SRM 2517a regularly conduct what we call production-related engineering experimentation.[7] These activities are an important aspect of production. The new more accurate measurement technology associated with SRM 2517a lowered the cost of these activities and hence represents a cost-savings benefit. Also experimentation costs for industry have been lowered because of industry's interaction with the NIST scientists that developed the artifact. One industry expert said SRM 2517a reduced his company's investigation costs and added that without it, the company would have invested additional engineering person-years with equipment to maintain production.[8]

- **Calibration cost savings**

SRM 2517a reduces the costs of calibrating production equipment and products. Examples, based on discussions with respondents in industry, follow.

It is not uncommon to recalibrate production devices for an optical fiber network on a daily basis, or even more frequently. SRM 2517a reduces the cost of each calibration; it permits equipment to be calibrated on the production floor. The alternative would be to purchase tunable lasers, which not only are more costly but also must be set for one frequency at a time, whereas the SRMs provide a fingerprint covering a whole range of the spectrum of wavelengths. In addition, tunable lasers entail additional operating time using well-trained technicians involved in production.

One respondent, whose company manufactures locked lasers and gas cells, observed that the alternative to SRM 2517a for calibration is to invest in a suite of equipment and then take the extra time to get the calibration results. A telecommunications company responded that prior to SRM 2517a it relied on its own internal standards based on one frequency and then extrapolated to other frequencies. The company's expert stated that the SRM 2517a standard, with multiple indicators of various frequencies, is a critically important advance for telecommunications.

- **Increased production yields**

Production yields have increased because SRM 2517a improved process control and thereby reduced the costs of product failure. Manufacturers of optical fiber network components produce to the customer's specifications and needs. SRM 2517a, as well as other SRMs in the 25xx series, provide useful reference points across a stable wavelength range for the tuning of the components for optical communications systems. As a costly and less accurate alternative, the points of reference could be simulated with expensive cascades of optical filters strung together.

A manufacturer of narrow-band optical filters told us: SRM 2517a provides narrow line widths for reference to absolute vacuum wavelengths and this is critical to meeting the performance specification needs of our customers. This artifact gives us an unquestionable reference to absolute wavelengths so that secondary standards can be recalibrated as they drift. With the alternative, over say 30 nm of wavelength range for a particular product, maybe 10 optical filters would be strung together. While the cost of the alternative is not that great, performance tolerances and wavelength stability would be lost. Using the alternative would have resulted in a yield loss of about 30 percent.

- **Negotiations cost savings**

Negotiations with customers over disputes about the performance attributes of products are reduced because of SRM 2517a and the traceability to the NIST standard that it provides. In the absence of wavelength stability, manufacturers and customers would both have grounds to disagree about performance characteristics. Without SRM 2517a and the traceability that it provides, costly negotiations and testing would occur. One respondent noted that without NIST traceability through SRM 2517a, interactions with the customers over performance characteristics would be like dealing with "a wound that would not heal."

- **Reduced marketing costs**

Marketing costs are reduced because SRM 2517a allows traceability of an important new standard to NIST, and sales are greater than for SRM 2517 because of the confidence inspired by the new standard traceable to NIST.

Paraphrasing a component manufacturer: There are two parts to the sales/marketing impact of SRM 2517a for our company. First, there is a savings in personnel costs because there is less effort needed to convince customers about the quality and reliability of our products. More importantly, there is a positive effect on our reputation and the customers' confidence in our product line because of having NIST standards integrated in the production process. That positive effect translates into extra sales and extra profits. Paraphrasing a manufacturer of wavelength meters: We use SRM 2517a as we manufacture wavelength meters. SRM 2517a is used to check periodically the calibration of test lasers and equipment used for the qualification of our wavemeters. We can claim traceability to NIST. There are cost savings to us in the sales/marketing category.

Quantitative estimates of each of the above categories of benefits were obtained from the five manufacturers with whom we spoke. According to Dr. Gilbert, these five companies collectively have purchased about 30 percent of the SRM 2517a cells sold to date. The benefit data in Table 6 captures industry-wide benefits. Each datum in Table 6 (and in the third column in Table 7) is the product of the sum of

TABLE 6. INDUSTRY BENEFITS TRUNCATED AT TEN YEARS (YEAR 2000 DOLLARS)

Year	Production Cost Savings ($1,000s)	Calibration Cost Savings ($1,000s)	Increased Production Yield ($1,000s)	Decreased Negotiation Costs ($1,000s)	Decreased Marketing Costs ($1,000s)
1999	3,193.9				
2000	3,266.5	401.0	2,613.3	245.0	473.7
2001	1,388.3	1,832.6	10,531.7	1,094.3	1,894.7
2002	1,682.3	353.5	2,106.3	218.9	383.0
2003	1,388.3	441.8	2,632.9	273.6	478.8
2004	1,388.3	589.7	3,514.2	365.2	639.0
2005	1,388.3	735.8	4,384.6	455.6	797.3
2006		846.8	5,046.5	524.4	917.7
2007		973.8	5,803.2	603.0	1,055.2
2008		1,119.9	6,673.7	693.4	1,213.5
2009		1,287.8	7,674.7	797.5	1,395.6

Note: See Table 8 for total industrial benefits. Production-related engineering and experimentation cost savings decrease in 2001 because, although some experimental production uses of the measurement technology were reported after the introduction of the SRM, the most intense realization of such experimental benefits came from the application of the new measurement technology—gained in industry's interaction with NIST through publications, presentations, and ongoing interaction with the researchers—to production problems encountered by industry as it coped with the need for the actual improved SRM and substituted experimentation for it. Observe (Appendix D) that publications about the SRM 2517a technology started appearing in 1999. The other categories of industry benefits increase after the introduction of the SRM 2517a because those benefits reflect the actual use of the SRMs once they were available for use.

the dollar values for each respondent multiplied by 3.33 (3.33 = 1/0.30), and all dollar values are converted to year 2000 dollars.

To be conservative, the estimated benefits from SRM 2517a are truncated after ten years. Respondents indicated that the SRM 2517a provided knowledge that would be commercially useful for the foreseeable future. Some respondents emphasized that, as a standard, the knowledge embodied in SRM 2517a would last and be useful virtually forever. However, industry may require even more development of the standards for measuring the wavelength of light as time passes, and the respondents as a group believed that a commercial lifetime of ten years would be a conservative estimate for the period of industrial use of SRM 2517a.

The observed variance in benefits (in year 2000 dollars) through time reflects three key things. First, there are different periods of primary incidence for the various cost savings. For example, production-related engineering cost savings occur primarily in the early years of the time series and in some cases even before the introduction of SRM 2517a.[9] In contrast, the costs of reduced yields (benefit of increased yields) are avoided throughout the time series after SRM 2517a was introduced and the technology transferred to industry. Second, the introduction of SRM 2517a occurred in late 2000 and partial-year benefits are reported; benefits increase in subsequent years since the SRM is used throughout each year. Third, the variance over time reflects the collapse of optical fiber communications industry sales from record highs in 2000–2001 to low levels in 2002. Projections by industry then reflect an expected recovery of industry sales to the levels experienced in 1999—levels that in 1999 were between one-third and one-half of their subsequent peaks in 2000–2001 before the bubble burst—by 2004–2005. Thereafter, the projections reflect what knowledgeable industry observers expect to be a 15 percent rate of growth.

The costs associated with the SRM 2517a project are in Table 7. The actual costs of the ATP intramural project are shown along with estimates of the pull costs for industry. Respondents were asked to estimate any initial costs, over and above any fees paid to NIST for SRM 2517a, to be able to use (i.e., pull in) the artifact in production. These pull costs are one-time costs.

TABLE 7. ESTIMATED COSTS ASSOCIATED WITH SRM 2517A (YEAR 2000 DOLLARS)

Year	ATP Funds ($1,000s)	Industry Pull Cost ($1,000s)
1998	72.6	
1999	76.7	
2000		16.3
2001		73.5

Table 8 aggregates the cost and benefit estimates from Tables 6 and 7.

TABLE 8. ESTIMATED TOTAL COSTS AND ESTIMATED TOTAL INDUSTRY BENEFITS ASSOCIATED WITH SRM 2517A (YEAR 2000 DOLLARS)

Year	Total Costs ($1,000s)	Total Industry Benefits ($1,000s)
1998	72.6	
1999	76.7	3,193.9
2000	16.3	6,999.5
2001	73.5	16,741.6
2002		4,744.0
2003		5,215.4
2004		6,496.4
2005		7,761.6
2006		7,335.4
2007		8,435.2
2008		9,700.5
2009		11,155.6

Results of the Economic Analysis

Table 9 summarizes the four evaluation metrics for this case study.

Based on one or all of the metrics in Table 9, the ATP intramural funded SRM 2517a project was successful from society's economic perspective. The internal rate of return is 4,400 percent, the benefit-to-cost ratio is 267 to 1, and the net present value in 2002 in year 2000 dollars is $76 million.

TABLE 9. EVALUATION METRICS FOR THE SRM 2517A CASE STUDY

Metric	Estimate
Real Internal Rate of Return	4,400%
Benefit-to-Cost Ratio	267 to 1
Net Present Value using 1998 as base year in year 2000 dollars	$58.1 million
Net Present Value using 2002 as base year in year 2000 dollars	$76.2 million

Appendix E presents an exploratory alternative estimation of the metrics in Table 9.

Notes

1. Because of fundamental molecular absorptions when light is projected through the absorption cell filled with acetylene gas, the power transmitted through the cell is distinct at specified wavelengths, allowing accurate references to those wavelengths. Those references can then be used to calibrate instruments for industry.
2. Gilbert and Swann (2001), p. 2.
3. See Appendix D for the publications, conference presentations, and research accomplishments associated with this project.
4. The data developed for discussion of the outcomes in this case study are based on discussions with Dr. Gilbert and several industry experts from Wavelength References, Burleigh Instruments, Corning, Agilent, and Chorum Technologies.
5. The information about the industry-wide coverage of our sample of respondents in industry was provided by NIST.
6. For a discussion of other optoelectronics SRMs, see: http://patapsco.nist.gov/srmcatalog/tables/view_table.cfm?table=207-4.htm.

7. Our understanding is that these activities fall under the rubric of research and development (R&D), but absent information about how companies classify these activities we refrain from using the policy-sensitive term "R&D."

8. See also the note to Table 6.

9. Industry interacts with NIST and stays abreast of the latest developments through direct communication with NIST scientists, and through scientists' presentations and publications. In this case, some respondents reported that they began benefiting from the new knowledge—gained from interaction with NIST researchers—about wavelength calibration even before SRMs were sold as industry coped with the need for the actual SRMs but substituted experimental work in their absence.

5 CASE STUDY OF Injectable Composite Bone Grafts

GOALS OF THE PROJECT

The goal of this project was to develop a new bone graft material superior to any product currently available for dental or orthopedic surgeries.

BACKGROUND INFORMATION AND OVERVIEW OF THE PROJECT[1]

The Polymers Division of the Materials Science and Engineering Laboratory has had a relationship with the American Dental Association (ADA) since 1928 through NIST's collaboration with the ADA's Health Foundation's (ADAHF) Paffenbarger Research Center (PRC).[2] Since early 1990, the Polymers Division has also enjoyed a research relationship with the National Institutes of Health (NIH) investigating the compatibility of new materials in the human body since the early 1990s.

In 1997, based on research in the Polymers Division sponsored by NIST, the National Institute of Dental and Craniofacial Research (NIDCR) of the NIH, and the ADAHF, a calcium phosphate cement was developed and introduced into the market by an ADAHF license under the name BoneSource®. According to the ADA:[3] "This plaster-like material can be placed surgically, molded and sculpted to the correct anatomical shape, and will set to form a hard implant composed entirely of hydroxyapatite. The implant material is slowly dissolved and replaced entirely by new bone, thus repairing the original defect." This material has successfully been used to repair cranial bone, but it has at least two problems that motivated Dr. Wang's intramural project. One, the cement does not disappear quickly meaning that the regeneration of new bone cells is slow. And two, the product could not be used in load-bearing areas in orthopedic surgeries.

In 1999, Dr. Francis Wang in the Polymers Division began a three-year ATP intramural project on the compatibility of new bone graft material in the human body. Dr. Wang received $409,000 over three years allocated as FY99: $100,000, FY00: $150,000, FY01: $159,000.

A number of key issues were addressed in the intramural project. One issue was to develop an alternative bone graft material that was "resorbable"—that is, the bone graft will dissolve away—referred to as "resorbing" the bone graft material. Another issue was to study additives that would rapidly regenerate new bone growth. As well, the material had to have enough mechanical integrity so that it would not migrate into the region outside of the area of the bone with a defect. And finally, the material needed to be biocompatible with surrounding tissue.

Dr. Wang found that tiny biodegradable polymer marbles that are 200 to 300 microns in diameter, called micro-spheres, could be mixed into calcium phosphate paste to occupy as much as 60 percent by volume to provide pores in which new bone cells can grow as the micro-spheres dissolve (over a three week period). The surgeon molds the paste into the defect, and the "marbles" disappear in about three weeks. While the micro-spheres are in the cement, they maintain the mechanical strength of the composite bone graft. Rather than encapsulate a growth factor protein in the micro-spheres, Dr. Wang demonstrated that the protein can be dissolved in the liquid part of the cement paste (made from calcium phosphate powder and liquid). Also developed during this project was a process that speeds the release of the growth factor protein. This process is related to the amount and type of microsphere particles added to the cement mixture.

Implications for Industry and Society

This ATP intramural project complemented the earlier research with NIDCR. Dr. Wang's project, building on the extant knowledge in the field, developed a new bone graft material superior to any product currently available for dental or orthopedic surgeries. This product is compatible with the human body, it maintains its integrity in that it does not migrate from the implanted area, and it rapidly stimulates new bone growth. As a result, its use is expected to benefit patients by reducing the time, cost, and discomfort associated with dental implant surgery, certain periodontal surgeries, and certain orthopedic surgeries.

Based on Dr. Wang's responses to the electronic survey, in the absence of the ATP intramural award, he would have undertaken a project with similar goals and milestones, as expected given that the project complemented on-going research in the Polymers Division.[4] However, this project in comparison to the hypothetical project is broader in scope and thus took longer to complete, was more technically challenging, and is expected to lead to more technical papers, new measurement technologies, and new databases.

Benefit and Cost Information[5]

From interviews it was learned that new enhanced calcium phosphate cements that use Dr. Wang's research results are projected to be marketable by 2006 and anticipated to have long-term social benefits. Although research in the field is expected to continue between now and 2006, it is anticipated that additional research will not change the findings of Dr. Wang's research and therefore will not diminish the social value of his findings or make them obsolete. According to Dr. Eichmiller, Dr. Wang's research could yield social benefits for as long as 30 years.

These new cement products are expected to yield the following benefits:

- **Reduce the cost of dental implants by 30 percent**

The time between the implant and the mounting of a tooth crown is expected to be reduced from 6 months to 2 months and hence the number of check-up visits with the oral surgeon will likewise be reduced. As a result, the respondents believe that costs will be reduced by 30 percent. Currently,[6] the average cost of a dental implant (not including the cost of the tooth crown) is between $1,500 and $1,800. In 2001 there were approximately 2.2 million implants in the United States.[7]

The value of the reduced cost of a dental implant can be estimated in terms of 2.2 million implants that cost, on average, $1,650 with current technology, and which will cost 30 percent less beginning in the year 2006 as a result of Dr. Wang's research. The aggregate savings are $1.09 billion (.30 × $1,650 × 2.2 million) in 2001 dollars.

- **Increase the success rate of periodontal surgeries**

There are currently two risks associated with periodontal surgeries (including osseous grafts and soft tissue grafts). The first risk, and this applies to orthopedic surgery, is associated with possible contamination from using freeze-dried cadaver bone from bone banks. The second risk is that the procedure will not be successful. At present, the success rate is between 60 percent and 70 percent, and the current average cost of a surgery is between $2,000 and $3,000. While the enhanced calcium phosphate cement is not expected to reduce the cost of a procedure, it is expected to eliminate the risk of contamination and increase the success rate to between

80 percent and 90 percent. In 2001 there were an estimated 800,000 grafts for which the new cement could have been used and thus could have increased the success rate of the graft.[8]

No dollar value of the benefits from the increased success rate of periodontal surgeries is quantified. There is certainly a physic benefit to consumers from receiving medical benefits from a procedure; however, those we talked with in the field suggested that when a periodontal surgery fails the patient rarely has it redone. Thus, there is no explicit cost saving to consumers, and oral surgeons are not financially worse off absent any impact on reputation.

- **Reduce recovery time from orthopedic surgeries**

Currently, ceramic phosphate cement is not used in load-bearing orthopedic surgeries because the recovery time is too long. At present, the turnover rate for bone regrowth is about 8 mm per year. The enhanced cement could be used in such surgeries and would decrease recovery time as well as post-recovery physical therapy time.

There is an explicit economic benefit to society from a recovering patient having less pain and suffering and being able to return to productive work sooner. However, absent information on the precise reduction in recovery time, the percentage of recovering patients who will return to work and the wage (marginal productivity) of those workers, this benefit is not quantified.

- **Allow orthopedic procedures on joints to become closed procedures**

On average, the fixture time to repair a joint fracture, a distal radius fracture (wrist), or a distal tibial pilon fracture (ankle) is between six and eight weeks, and the average cost when surgery is needed for these fractures is between $6,000 and $10,000. This cost would fall by about 50 percent if a closed procedure were used, that is, if enhanced cement were injected into the fractured area as an alternative to surgery. In general, the cost of a closed orthopedic procedure is about one-half of one involving intervention. In 1999 there were 650,000 bone grafts, and a closed procedure would have been applicable on approximately 10 percent to 20 percent.[9]

The cost to harvest a patient's own bone, typically about $1,000, would also be avoided with a closed procedure. To avoid possible contamination from freeze-dried bone from a bone bank, it is common during reconstructive orthopedic surgery for bone to be taken from the patient's iliac to use in the reconstruction.

The value of the reduced cost of an orthopedic procedure, due to conducting a closed procedure rather than using invasive surgical intervention, can be estimated in year 2001 dollars in terms of 97,500 bone graft patients ($.15 \times 650{,}000$) having saved, on average, $5,000 ($4,000 + $1,000). This translates to an annual aggregate savings of $487.5 million.

Based on the interview information, the following conservative assumptions underlie the timing of these economic benefits.

First, it is assumed that the enhanced bone cement will take one full year to penetrate the market. Those with whom we spoke who are currently involved in selling bone cement products (i.e., pharmaceutical representatives) and those who have knowledge of the various procedures in which the new product will be used expected that the new product would penetrate the market in less than six months, based on their experience with the current bone cements that are available.

Second, the projected number of procedures referenced above for each category of consumer cost savings is not assumed to increase over time, although as noted the trend is certainly increasing.

Third, while there is the expectation that social benefits will extend well beyond 2016, future benefits for only 10 years are considered. Although at the time of this study, Dr. Wang's research results are authoritative and no new technological advances are forecast, forecasting future research results is not an exact science. Our discussions with Dr. Wang and Dr. Eichmiller led us to conclude that, absent ATP's support of this project, the private sector would not easily, if at all, have duplicated his results.[10] But since that assumption is conjecture, the inclusion of only 10 years of benefits removes any biases from our analysis that would be associated with that point given that if the private sector did eventually duplicate his results it would have had to do so after the fact.

Costs include ATP funding of Dr. Wang's research project, plus potential expenses industry will incur to develop and market the cement and medical practitioners' costs to use it. The three pharmaceutical representatives who offered insights about this cement—and all three were given the published references in Appendix D—conveyed that their contacts in corporate R&D were of the opinion that once the product was on the market companies would have to add little to it before marketing it.[11] When queried, the amount that each company reported expecting to add to market the product was "less than $250,000." Using $245,000 for total company marketing costs and assuming that each of the five pharmaceutical companies will allocate costs evenly over the years 2002 to 2006, the annual total costs by this industry segment to bring Dr. Wang's research to market is $245,000.

The five surgeons with whom we spoke about this cement told us that it would be very easy to use and would likely be accompanied by a video training tape, thus making the learning time less than one hour. As this means that pull costs are relatively insignificant in this analysis, they are therefore ignored.

Table 10 compares the ATP allocations to fund Dr. Wang's project in years 1999, 2000, and 2001 (converted from nominal values to year 2000 dollars) to the projected social benefits associated with savings from that project (in year 2000 dollars) with a one-year lag from 2006 to 2007 to account for the time needed for the new product to penetrate the market. These projected social benefits are, in our opinion, a combination of consumer and producer benefits.

TABLE 10. ESTIMATED TOTAL COSTS AND ESTIMATED TOTAL SOCIAL BENEFITS ASSOCIATED WITH INJECTABLE COMPOSITE BONE GRAFTS (YEAR 2000 DOLLARS)

Year	ATP Funds ($1,000s)	Private Sector Marketing Costs ($1,000s)	Estimated Social Benefits ($billions)
1999	102.3		
2000	150.0		
2001	155.8		
2002		245.0	
2003		245.0	
2004		245.0	
2005		245.0	
2006		245.0	
2007			1.55
2008			1.55
2009			1.55
2010			1.55
2011			1.55
2012			1.55
2013			1.55
2014			1.55
2015			1.55
2016			1.55

There are no *a priori* reasons to believe that the dental and surgical procedures described above occur in competitive markets, and no information was learned during our interviews to suggest that such was the case. Thus, some portion of the calculated benefits will be passed along to consumers and some portion will be retained as producer profits.

The impact of those benefits is expected to be extraordinarily large. Even if we knew the amounts of the investment costs for the follow-on research and included them in the metrics on the assumption that they were necessary for commercialization of Dr. Wang's results, the social rate of return would be extraordinarily high.

Results of the Economic Analysis

Table 11 summarizes the four evaluation metrics for this case study. Each was calculated using the data in Table 10.

TABLE 11. EVALUATION METRICS FOR THE INJECTABLE COMPOSITE BONE GRAFT CASE STUDY

Metric	Estimate
Real Internal Rate of Return	230%
Benefit-to-Cost Ratio	5,400 to 1
Net Present Value using 1999 as the base year in year 2000 dollars	$6.8 billion
Net Present Value using 2002 as the base year in year 2000 dollars	$8.3 billion

Based on one or all of the metrics in the table above, the ATP intramural funded bone grafts project was successful from an economic perspective. The internal rate of return is 230 percent, the benefit-to-cost ratio is 5,400 to 1, and the net present value in 2002 in year 2000 dollars is over $8 billion.

Notes

1. Much of this background information came from a face-to-face interview with Dr. Wang on October 23, 2001 at NIST, and from subsequent correspondence. Also, Dr. Fred Eichmiller, director of the American Dental Association Health Foundation Paffenbarger Research Center at NIST, provided useful information through extensive telephone interviews.

2. Background information on the Paffenbarger Research Center is at www.adahf.org/paffen.html.

3. See http://www.adahf.org/ada/prod/adaf/paffenbarger/prog_bone.asp, Calcium Phosphate Bone Cement PRC Research Program.

4. Appendix D lists the publications, conference presentations, and research accomplishments associated with this project.

5. This section is based on extensive telephone discussions with Dr. Fred Eichmiller of the ADA, Dr. John Rendall at the University of North Carolina Medical School, and Mr. John Ruesch at the ADA Survey Research Center.

6. Because these interviews were conducted in early and mid-2002, it is assumed that these and other such cost saving estimates reflect costs in 2001.

7. According to the ADA Survey Research Center, there were 640,000 dental implants in 1990 and the growth rate has been over 12 percent per year.

8. According to the ADA Survey Research Center, there were 230,000 osseous grafts in 1990 and a 12 percent annual growth rate was used to project the number in 2001.

9. The 1999 estimate came from the U.S. Department of Health and Human Services, and that number increased at about 30 percent per year during the 1990s. See *Statistical Abstract of the United States, 2001,* Table 168.

10. Several pharmaceutical companies, such as Johnson & Johnson, do market grafting cements. Discussions with marketing representatives from these companies, who in turn said that they discussed our queries with those in corporate R&D, verified that the pharmaceutical industry did not have injectable grafting materials on their near-term research agendas.

11. These individuals did not want to be identified, and neither did the contact person in corporate R&D.

6 CASE STUDY OF Internet Commerce for Manufacturing

GOALS OF THE PROJECT

The goals of this project were to:

- assist industry in developing open standards to enable exchange of business and product data for all supply chain participants,
- provide a flexible testbed for industry and government to collaborate in testing and evaluating standards-based tools and integration technologies, and
- demonstrate business-to-business (B2B) electronic commerce (e-commerce).

BACKGROUND INFORMATION AND OVERVIEW OF THE PROJECT[1]

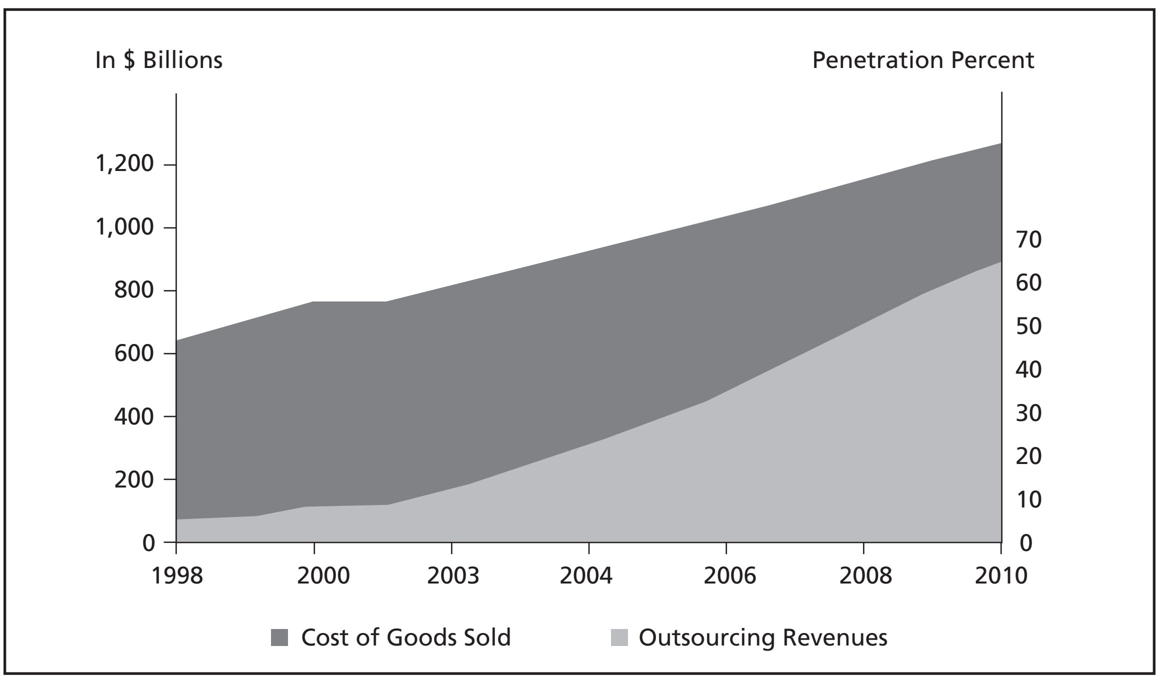
In 1998, Mr. Thomas Rhodes in the Software Diagnostics and Conformance Testing Division of the Information Technology Laboratory (ITL) and Ms. Barbara Goldstein in the Electricity Division of the Electronics and Electrical Engineering Laboratory (EEEL) began a three-year cross-laboratory multi-researcher ATP intramural project to address problems facing companies that rely on the Internet for business-to-business electronic commerce. More specifically, the Internet Commerce for Manufacturing (ICM) project focused on the printed circuit board fabrication and assembly manufacturing process and the industry and trading partners that are involved in the life cycle of activities of manufacturing and assembling electronic boards. The other laboratories/groups with personnel involved in this project were the Manufacturing Engineering Laboratory (MEL) and the Manufacturing Extension Partnership (MEP) Program. This group received $580,000 over three years allocated as FY98: $200,000, FY99: $230,000, FY00: $150,000.

As Figure 3 illustrates, at the time of the ATP intramural project proposal, original equipment manufacturers (OEMs) in the computer industry, such as Hewlett-Packard, Intel, Lucent Technologies, and Motorola, were beginning to rely on contract manufacturers in the electronics manufacturing services (EMS) industry for the engineering and manufacturing of components to be used in printed circuit boards (PCBs).[2]

Because of this trend and its expected growth, and because of increased complexity and density of PCBs, industry was expressing great concern about the need for Web-based data sharing and for reliable mechanisms for the exchange of design and performance data. According to Mr. Rhodes and Ms. Goldstein, the IPC was aware of NIST's work on such standards as GenCAM (discussed below) through interaction with NIST scientists in RosettaNet,[3] a consortium of between 500 and 600 information technology companies worldwide.[4] Also, in 1998, the National Electronics Manufacturing Initiative (NEMI)[5] Technology Roadmap identified the lack of interoperability among applications in e-commerce as one of the greatest barriers for the industry of manufacturers of mechanical and electronic components, especially the small and medium-size manufacturers.

The ATP intramural project was conceived by the two researchers as a response to OEM needs in particular. MEL's interest in the project stemmed from its interest in improving the manufacture of PCBs; ITL was interested in infrastructure and architecture issues to enable e-commerce; EEEL was interested in assisting industry to

FIGURE 3. PERCENTAGE OF POTENTIAL CONTRACT MANUFACTURING REALIZED BY THE EMS INDUSTRY



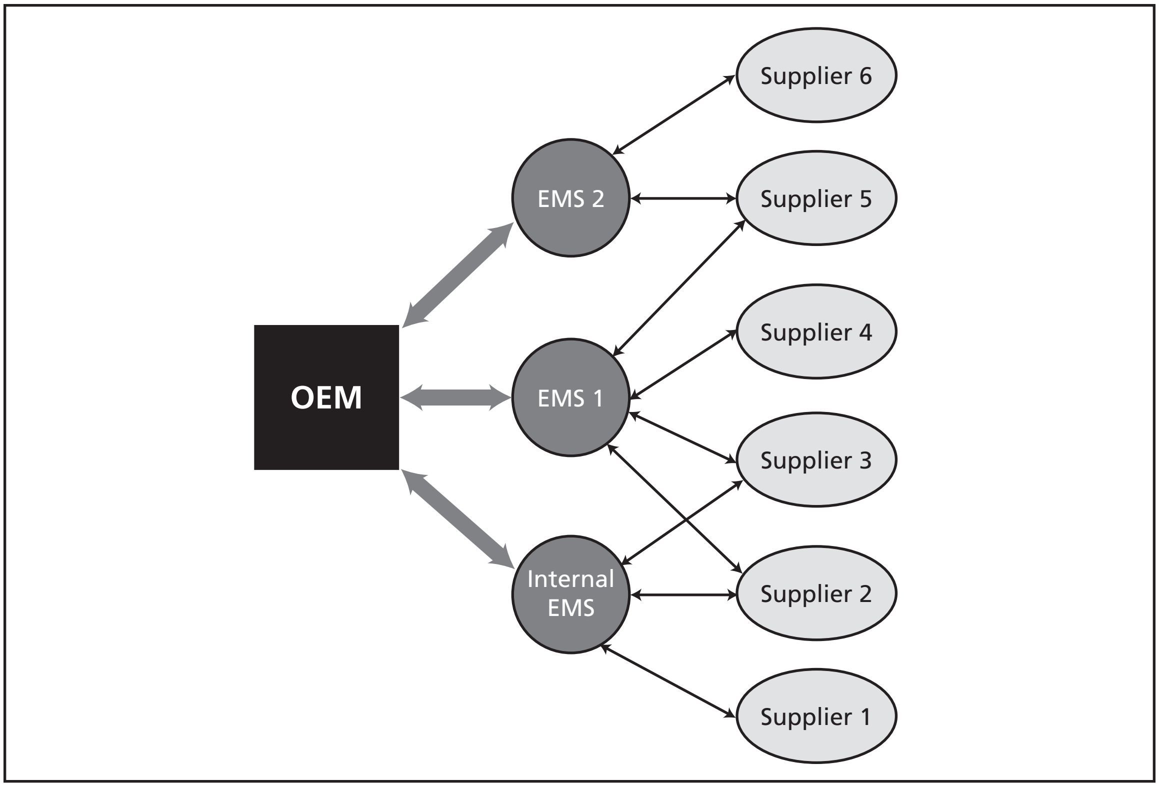
Source: Goldman Sachs.

more efficiently form and maintain supply chain partnerships in order for the industry to best compete in the global marketplace; and MEP was looking for solutions that could assist small and medium-size companies become involved in e-commerce.

ICM had the same broad objectives as RosettaNet, but the ICM project focused farther downstream in the supply chain. The ICM project focused on the design and manufacturing of PCBs. RosettaNet's goal was to develop a set of Web-based standards for trading partners in the IT industry so that these companies could begin to engage in e-commerce.

ICM directly involves the PCBs assembly supply chain.[6] OEM companies at the bottom of the supply chain originate the product structure and feed it to the upstream partners. Once this process begins, various designs for assembly, fabrication, test feedback and material status, work-in-progress, and quality information flow back to the OEMs. Because OEMs will be feeding and receiving information from a number of external EMS companies, and perhaps some that are internal, OEMs need methods to interpret accurately the feedback information and to respond in a way that will be universally understood. Figure 4 illustrates the complexity of this information exchange, taking into account that EMS companies

FIGURE 4. SUPPLY CHAIN INFORMATION EXCHANGE



themselves have to interact with their suppliers, and often a given supplier services more than one EMS company.

OEM and EMS companies are emphasized in this case study.

At the time that this project began, the initial version of GenCAM (IPC 2510) was about ready to be released. NIST played an important role in the promulgation of this standard, but that work was outside the ATP-funded ICM project. The GenCAM standard described PCBs and their assembly in sufficient detail for designated boards to be manufactured and assembled by the EMS. GenCAM, however, did not facilitate high-level supply chain communication of business and product definition data.

The technical approach of the ICM project was to work closely with industry through standards development organizations and industry consortia to develop candidate standards, to test those standards in an open testbed, and to assess the feasibility of using such standards in conjunction with other standards (e.g., GenCAM).

All the objectives of the project were met and all the related activities have collectively benefited industry. The one activity that could clearly be isolated as a direct result of the ICM project, and thus became the evaluation focus of this study, is the formulation and adoption in November 2001 of the following Product Data eXchange (PDX) standards:

- IPC-2571, Generic Requirements for Electronics Manufacturing Supply Chain Communication
- IPC-2576, Sectional Requirements for Electronics Manufacturing Supply Chain Communication of As-Build Product Data
- IPC-2578, Sectional Requirements for Supply Chain Communication of Bill of Materials and Product Design Configuration Data.

The project also led to the IPC-2577 proposal for Sectional Requirements for the Supply Chain (B2B) Communication of Quantity Product Data, but our focus is exclusively on the PDX standards.[7]

Because the ICM project was initiated in part in response to the NEMI roadmap, and because NIST had previously helped to launch, manage, and contribute technically to the NEMI Virtual Factory Information Interchange Project (VFIIP), those involved in the ICM project were well positioned to design and complete the ICM project.

In addition, the project led to the adoption of a sectional GenCAM requirement, IPC-2511-19, and to a RosettaNet standard, PIPS 2C1-10. However, the remainder of this case study focuses only on the economic effects traceable to the PDX standards because that work is a stand-alone accomplishment that is directly traceable to the ICM project and can uniquely be identified by those in the industry.

Implications for Industry and Society

Based on Mr. Rhodes' and Ms. Goldstein's responses to the electronic survey for the ICM team, this ATP-funded ICM project both complemented ongoing research activities at NIST—in the three separate laboratories represented in the project—and also fostered new initiatives in researching, developing, and testing new technology and specifications for e-commerce in manufacturing.[8]

Ongoing NIST research traditionally involved development and testing of open standards and underlying technologies targeted toward improving software and systems integration and interoperability. The ICM project, however, focused on the emerging technologies and standards for e-commerce and their potential use toward improving supply-chain integration among companies engaged in the design and manufacture of electronic printed circuit boards and assemblies. Rather than simple catalog-based ordering over the Web (i.e., B2C), e-commerce for manufacturing involved more complex build-to-order processes, referred to as business-to-business e-commerce. The ICM project helped focus NIST efforts toward investigating technologies, such as XML, agent technology, ontologies, semantic resolution, distributed object models, etc., that could support the dynamic requirements of B2B e-commerce. Today, various projects within NIST laboratories (ITL, EEEL, MEL, BFRL, MEP) continue to pursue these research areas with an eye toward supporting e-commerce for manufacturing and assisting industry in developing specifications and tools based on suitable technologies.

Without ATP funding, it is highly unlikely that the goals and milestones of the ICM project ever would have been funded. Efforts were made to secure funding from the NIST National Advanced Manufacturing Testbed (NAMT) project, which endorsed the ICM project, but which did not have available funds to support ICM. Further, until ATP funding was obtained, internal laboratory funding was also unavailable. Hence, ATP funding made the ICM project feasible.

As shown in the supply chain in Figure 4 above, PDX standards have the potential to affect three levels: OEMs, EMS companies, and the EMS suppliers. Only the first two levels of the supply chain are considered in the analysis that follows. There is a pragmatic reason for limiting the levels of analysis. Based on telephone interviews with industry experts,[9] at most 2 to 3 percent of the component suppliers' industry is just beginning to use aspects of the PDX standards that were approved in November 2001. Component suppliers are the level in the supply chain expected by EMS companies to increase conformance over time. These EMS suppliers cannot approximate the benefits from PDX standards because the EMS-to-supplier interface for the most part has not yet begun to embrace the use of all of the PDX standards.

The consensus expressed in telephone interviews with industry experts is that OEMs and EMS companies not only were the first in the supply chain to use the standards, but also began to realize cost-saving benefits from the PDX standards even before they were finalized by the IPC.

Benefit and Cost Information

The benefits quantified in this case study reflect cost savings due to the companies receiving the benefits of the PDX standards developed in the ATP project sooner than if they had evolved from industry's initiatives. The consensus opinion expressed by individuals interviewed at OEM companies was that cost savings were realized by both OEM and EMS companies beginning in 2001.

For OEMs:

- The average cost savings per interviewed OEM, in terms of man-years saved due to improved communication with contractors in 2001, was 2 to 3 man-years of savings, where a fully burdened man-year is valued at $225,000, for an average major OEM savings of $562,500 ($225,000 × 2.5 man years) (in year 2001 dollars).
- At the time of the interviews, only the major OEMs were using the PDX standards for communication with the EMS industry, so a conservative estimate of cost-savings for the $500 billion (in year 2001 dollars) OEM industry could be derived by using a multiple of 10 (i.e., 10 major OEMs). Over time, other OEMs would certainly adopt the PDX standards, but no estimates were given for the rate of diffusion of the standard. Therefore, benefits are conservatively estimated under the assumption that the adopting population equals the 10 major OEMs.
- NIST's role through the activities of the ICM project hastened the promulgation and adoption of the PDX standards by the OEMs by at least 2 years.[10] The OEMs are of the opinion that absent NIST's role, the adoption of the PDX standards would have been delayed by at least 2 years from the date of the interviews, meaning that benefits could have been realized in 2004. Thus, benefits from the

ICM project to OEMs were realized in years 2001, 2002, and 2003. These benefits (in year 2001 dollars) per year are $5.625 million ($562,500 × 10 OEMs).

- OEMs did not have an opinion as to how long the PDX standard will last. To be conservative, we truncate benefits to OEMs at year 2004 and measure only the benefits due to the acceleration of the PDX standards caused by NIST's funding.

For EMS companies:

- The average interviewed EMS cost savings was 1 to 1.5 man-years per year. This estimate was derived on the basis of 200 to 300 man-hours saved on data translations per customer for each of, on average, 10 major customers. Thus, each EMS using the PDX standards saved 2,000 to 3,000 man-hours in 2001. Using the suggested fully-burdened rate of $175,000 for a fully-burdened man-year in the EMS industry, the average savings was $218,750 ($175,000 × 1.25 man years) (in year 2001 dollars).
- At the time of the interview, only about 10 percent of the $180 billion domestic EMS industry was using the PDX standards, but this percentage is expected to increase over time as the EMS industry is forecast to grow at 25 percent per year.[11]
- A conservative estimate for cost-savings to the EMS industry can be derived by using a multiple of 5, for the five major contractors. While smaller EMS companies are adopting the PDX standards, these five are ahead of the curve. These benefits (in year 2001 dollars) per year were $1.094 million ($218,750 × 5 EMS companies).
- NIST's role through the activities of the ICM project hastened the promulgation and adoption of the PDX standards by the EMS industry. Absent NIST, such standards would eventually have been promulgated from the EMS side, but not until at least 5 years from the date of the interviews.[12]
- Those interviewed in the EMS industry are of the opinion, averaged from all responses, that benefits from the adoption of the PDX standards will last at least 8 to 10 years. Thus, benefits from the ICM project to the EMS industry were and are conservatively expected to be realized for only 8 years—2001 though 2008—and are reasonably projected farther out than benefits to the OEM industry.[13]

Costs included in the analysis were limited to ATP funds. None interviewed experienced significant pull costs associated with adopting the PDX standards.

Table 12 compares the ATP allocations to the ICM project in years 1998, 1999, and 2000 to the projected social benefits associated with savings from that project. All estimates are in year 2000 dollars.

TABLE 12. ESTIMATED TOTAL COSTS AND ESTIMATED TOTAL SOCIAL BENEFITS ASSOCIATED WITH ICM (YEAR 2000 DOLLARS)

Year	ATP Funds ($1,000s)	Estimated Social Benefits ($1,000s)
1998	207.4	
1999	235.2	
2000	150.0	
2001		6,580
2002		6,580
2003		6,580
2004		1,080
2005		1,080
2006		1,080
2007		1,080
2008		1,080

RESULTS OF THE ECONOMIC ANALYSIS

Table 13 summarizes the four evaluation metrics for this case study. Each was calculated using the data in Table 12.

TABLE 13. EVALUATION METRICS FOR THE INTERNET COMMERCE FOR MANUFACTURING CASE STUDY

Metric	Estimate
Real Internal Rate of Return	220%
Benefit-to-Cost Ratio	33 to 1
Net Present Value using 1998 as the base year in year 2000 dollars	$17.7 million
Net Present Value using 2002 as the base year in year 2000 dollars	$23.2 million

Based on one or all of the metrics in the table above, the ATP intramural funded ICM project was successful from an economic perspective. The internal rate of return is 220 percent, the benefit-to-cost ratio is 33 to 1, and the net present value in 2002 (in year 2000 dollars) is $23 million.

NOTES

1. Much of this background information came from a face-to-face interview with Mr. Rhodes and Ms. Goldstein on October 23, 2001 at NIST, and from subsequent correspon-

dence with both of them. During the telephone interviews with industry experts, much of the background information in this section was discussed in an effort to focus the interview.

2. See www.jabil.com.

3. See www.rosettanet.org.

4. In 1999, the IPC changed its name from Institute of Interconnecting and Packaging Electronic Circuits to IPC. Now, the organization is known as IPC—Association Connecting Electronics Industries. See www.ipc.org.

5. See www.nemi.org. Information on the related NEMI Factory Information System (FIS) is at www.fis.nemi.org.

6. See IPC-2571 at http://www.gencam.org.

7. By delimiting the evaluation focus of the study to PDX standards we made the study tractable but at the same time delimited the estimable benefits.

8. The publications, conference presentations, and research accomplishments associated with this project are in Appendix D.

9. This section is based on extensive telephone discussions with individuals identified by Mr. Rhodes and Ms. Goldstein. The recommended contact individuals represent companies throughout the supply chain, including OEMs Lucent, Agilent (spin off from Hewlett-Packard), and Intel, and EMSs Sanmina-SCI, Router Solutions, and Teradyne. Individuals from the IPC were also contacted.

10. Those interviewed were, as expected, not familiar with the ICM project at NIST, but they were familiar with the critically important role of those involved in the ICM project during the period of the ICM project.

11. See www.ableco.com.

12. This was an interesting observation since part of the motivation for the ICM project was pressure from OEMs to develop such standards.

13. A case could be made that OEM benefits should be forecast for the same length of time as benefits to the EMS industry since the PDX standard affects both parties.

7 CASE STUDY OF Polymer Composite Dielectrics for Integrated Thin-Film Capacitors

Goals of the Project

The goals of this project were to establish new metrology to characterize electrical properties of embedded capacitance in printed wiring boards and advance knowledge about the limits of this new system.

Background Information and Overview of the Project[1]

In 1999, Dr. Jan Obrzut in the Polymers Division of the Materials Science and Engineering Laboratory began a three-year ATP intramural research project to develop knowledge about the electrical properties of thin-film polymer composite dielectric materials[2] used as embedded capacitance[3] for printed wiring boards. Dr. Obrzut received $260,000 over three years allocated as FY99: $70,000, FY00: $70,000, and FY01: $120,000.

This research project grew from the needs of industry for new thin-film embedded passive materials, fabrication processes that are compatible with the new printed circuit boards with embedded capacitance, and broadband testing of the materials at frequencies of 500 MHz to 10GHz.

The project successfully met its three objectives:

- to advance measurement science by developing a technique for testing the microwave broadband permittivity of dielectric films with a high dielectric constant,[4]
- to develop the practical application important for industry of broadband impedance[5] characterization of dielectric films for embedded capacitance, and
- to contribute to materials science by developing fundamental understanding of high-frequency dielectric properties in polymer-ferroelectric ceramic composites.[6]

Dielectric films can be used in the new packaging solutions for the high-performance chips combining resistors, capacitors, and microstrips with integrated circuits in printed circuit boards. The new solutions provide the necessary terminations, decoupling, and interconnects for the operation of broadband high-frequency communications systems. The embedded capacitance, using dielectric films with high dielectric constants and low dielectric loss, allows the systems to operate at high frequencies by providing a low-impedance power plane.[7] The embedded capacitance also reduces the space taken by capacitors, allowing miniaturization or additional features and hence more functionality from the board.

The low impedance of the power plane is the essential requirement for microwave packaging. A key problem in microwave processing currently is that every interconnection creates more impedance. To address the need for low impedance of the power plane with embedded capacitance, industry is looking for new dielectric composite materials.

IMPLICATIONS FOR INDUSTRY AND SOCIETY

The new technology developed in the intramural project allows characterization of the embedded capacitance used for decoupling (i.e., decreasing power plane impedance) and that capacitance is needed in the high-speed electronics used in the transmission of information in communications systems. At the time that the ATP-funded project was concluding in 2001, the customers for the resistors, capacitors, and dielectrics used for interconnects included GSM Global System for Mobile Communications (the European standard) then operating at 900 MHz (and migrating to 1.8 GHz), Digital Cordless Standard (also European) GSM 1800 operating in the 1.8 GHz range (and migrating to 3.6 GHz), and iDEN Integrated Digital Enh. Network (a Motorola standard, U.S.) operating at 800 MHz, 900 MHz, and 1.5GHz (and migrating to 3.0 GHz) bands.

All of those applications were developed based on functional testing—there was an iterative process, then the dielectrics were tuned, and finally the functional performance was developed. In the iterative process of functional testing, the communications between materials suppliers and users were not well informed. They did not talk the same language, because the consumers, the device producers, did not know what to say about the dielectric constant they required, and the materials providers did not know what to provide. There was no testing procedure to bridge the different languages used by the materials suppliers and the materials users.

Dr. Obrzut's research has provided the needed procedure and a base of knowledge about the properties of the materials. For these reasons, the ATP intramural project will have important impacts on industry.

NIST has been a member of the Embedded Decoupling Capacitance (EDC) Industrial Consortium that framed the theory and the applications and the measurement science for integrated passive devices embodying embedded capacitance. The consortium has met frequently and regularly beginning in 1997, and the outputs of the ATP intramural research project informed the work of the consortium. Industry formulated what was needed—passive devices providing low-impedance power planes. NIST showed that polymer composites have the properties industry needs. NIST provided accurate high-frequency permittivity and impedance characteristics data for several dielectric films with high dielectric constants that were developed by industry for the embedded decoupling capacitance applications in high-speed electronics. The dielectric films for which NIST provided characteristics data include 3M's C-Ply, HADCO's EmCap, and DuPont's HiK.

NIST's research also led to the discovery that an embedded capacitance layer made of polymer composites with high dielectric constants can provide the desired low impedance characteristic better than any other known packaging solution for the high-performance chips combining resistors, capacitors, and microstrips with integrated circuits in printed circuit boards to provide the necessary terminations, decoupling, and interconnects for the operation of broadband high-frequency communications systems. Also, in the ATP intramural project, NIST initiated work on a new IPC standard dielectric test method in the range of 100 MHz to 10 GHz. The NIST work is in the public domain; everyone can look at the work and benefit from it.

The ATP-funded project for NIST complemented and accelerated the research agenda of the Polymers Division. Dr. Obrzut described its impact[8,9] on industry as follows: "This program was within the laboratory mission to initiate and expand its research capabilities on dielectric properties of organic polymers and composites at microwave frequencies.[10] The program started in 1999 and concluded in 2001. As a result we developed a new broadband testing methodology for dielectric films. Subsequently, we discovered and then characterized a high-frequency relaxation process in polymer composites, which is important for practical applications. Since the method enables measurements at microwave frequencies, it is attractive for both the industry and academic research."

Benefit and Cost Information[11]

Discussions with industry reveal several categories of benefits, most of which are potential benefits because the embedded capacitance technology is still being developed. The categories for industrial benefits from the ATP-funded dielectrics project are materials characterization savings, improved production yields and negotiation cost savings, and the enabling of new products.

Once the new IPC dielectric test standard is ready and the embedded capacitance technology fully developed, industry expects benefits to result from being able to characterize the materials and better understand their performance at high frequencies in developing materials for OEMs. At that time, the benefits would be quantified as lower costs for materials suppliers characterizing dielectric materials and for board fabricators verifying the performance of materials. Further, the test method is expected to result in accurate characterization of materials allowing higher production yields for both materials suppliers and the board fabricators. Finally, the test method will enable new products for the materials suppliers, the board manufacturers, and the OEMs as the embedded capacitance technology becomes a commercial reality.

Industry respondents reported that the impact of Dr. Obrzut's research to date has been on materials suppliers. The materials suppliers have benefited in that they can now effectively communicate about the performance characteristics of the materials in high-frequency applications. Industry experts expect the commercial lifetime of the thin-film dielectric materials and the testing methodology to characterize them to be at least 20 to 25 years.

- **Materials characterization savings**

Dr. Obrzut's test method will reduce the costs of characterizing materials. Instead of relying on trial and error, the test will give accurate information about the properties of dielectric materials being used.[12] There are two important aspects. First, the new metrology allows industry to understand clearly the performance of the materials themselves. With the other existing methods, the characterization of the performance of the thin-film dielectric materials is not adequate in certain frequency ranges of interest. Second, when a printed circuit board is designed, designers will have more information about what performance to expect once the material is in a board. In the past, designers have relied on the materials' performance characteristics when tested at low frequencies. The actual performance of the materials once in the board and operating at high frequencies was unknown.[13]

The supply chain of interest here is: materials suppliers, board fabricators, and then OEMs. Only those in the first two stages of the supply chain will realize materials characterization savings from the test method. OEMs will be measuring board characteristics from the surface of the board, so a different test will be used.[14]

- **Production yield increases and negotiation cost savings**

The production yield of board fabricators and OEMs will increase with Dr. Obrzut's test method in place and thus their production costs will decrease.

Similarly, performance disputes among materials suppliers, board fabricators, and OEMs will decrease again decreasing production costs.[15]

- **Enabling new products**

Dr. Obrzut's test method will enable industry to move forward into new products with higher frequencies, enabling broader bandwidth communications technology with greater output flow. As a result, future sales will increase.[16]

Technology to use embedded capacitance is still being developed; therefore, it was not possible to obtain *separate* quantitative estimates of each of the categories of benefits from our respondents in industry. Instead, we are able to make a conservative estimate of the aggregate of the average annual benefits using a different approach. We asked the respondents how much they would have invested in the project if NIST had not been involved; their response became the basis for estimating a lower bound for what industry expected the benefits of the project to be.

Table 14 provides the time series for the costs of the ATP intramural dielectrics project (in year 2000 dollars). Respondents were asked to estimate any "pull costs." Such costs are initial costs, over and above any fees paid to NIST for the outputs of the NIST research, required to make use of the new test method in a company. The pull costs are one-time costs incurred prior to the in-house use of the test method. Discussions with industry show that there were essentially no discernable pull costs for industry because the new knowledge was assimilated in the course of the ongoing work of the EDC consortium members. However, industry did make in-kind

TABLE 14. ESTIMATED TOTAL COSTS AND SOCIAL BENEFITS ASSOCIATED WITH THE DEVELOPED TEST METHOD (YEAR 2000 DOLLARS)

Year	Costs ($1,000s)	Lower-bound Expected Benefits ($1,000s)
1999	71,600 + 371,535 = 443.135	
2000	70,000 + 363,233 = 433.233	
2001	117,600 + 610,231 = 727.831	
2002	—	
2003	—	
2004	—	1,380
.		.
.		.
.	—	.
.		.
.		.
2020	—	1,380

contributions to Dr. Obrzut's research project, contributing equipment, materials, and expertise of industry experts. Industry respondents estimated that those in-kind contributions through the EDC consortium were worth $1,345,000.[17] The costs for those in-kind contributions have been spread throughout the three years of the NIST project in the proportion of the annual NIST costs for the project. Thus, for 1999, 2000, and 2001, NIST's costs (in year 2000 dollars) were $71,600, $70,000, and $117,600 respectively. The costs for the in-kind contributions from industry are then $371,535, $363,233, and $610,231 for 1999, 2000, and 2001, respectively.

Also shown in Table 14 are lower bounds for the aggregated estimates for the expected benefits to industry at the time that the investments in the project were made. The benefits from being able to accurately characterize the dielectric materials, higher production yields, reduced negotiation costs, and enabling new products are potentially large but as yet are unrealized. However, we are able to make a conservative estimate of the average annual benefits. In the table, our estimate for those potential unrealized benefits is indicated as $1,380,000 for the expected average annual profits beginning in 2004 and lasting conservatively until 2020 (respondents indicated an expected commercial lifetime for the embedded passive devices technology of at least 20 to 25 years). These expected benefits begin in 2004 based on the report of well-informed respondents.[18]

The expected average annual profits reported in the table were based on industry responses to a hypothetical investment decision. Discussions were conducted with knowledgeable respondents about what would have happened if NIST had not funded Dr. Obrzut's project. Under that scenario, it is reasonable to assume that—given the market conditions and expectations at the time when the NIST project began—beginning in 2000, each of the four prominent materials suppliers that participated in the EDC consortium individually would have invested the amounts that were invested in the NIST project. Thus, for the four suppliers together there would have been $1,772,540, $1,732,932, and $2,911,324 invested in 2000, 2001, and 2002, respectively. In return, future profits would be expected to flow from 2004 through 2020.

To make the investment, industry would have required that the future profits be sufficient for the investment to return a yield exceeding a hurdle rate. The lower that hurdle rate, the lower the expected future profits would need to be for the investment to be worthwhile for industry. From work with industry, it is known (Link and Scott, 2001) that for risky R&D investments industry typically would require a much higher hurdle rate than the 7 percent real rate recommended by OMB as the opportunity cost of public funds. We conservatively apply a hurdle rate of 15 percent, and ask what average annual expected profits would have had to be over the years 2004 through 2020 to yield a 15 percent rate of return on the investments that industry would have made absent the NIST dielectrics project.

That average annual expected profit for the industry is $1,380,000 (in year 2000 dollars), and it is shown in Table 14 as annual benefits. Note that those average annual expected profits are just a bare-minimum, lower-bound on what expected profits would have been, since the estimated amount is just barely enough for the hurdle rate to be reached, and further the hurdle rate is a very conservative one that surely underestimates the one that industry would have used. Expected annual profits of those actually making such an investment decision would surely have been much greater. They have not been realized to date, however, so the conservative, lower-bound estimate of $1,380,000 for the average annual profits is used.

Results of the Economic Analysis

Table 15 summarizes the four evaluation metrics for this case study. Each was calculated using the aggregate data in Table 14.

TABLE 15. EVALUATION METRICS FOR THE DIELECTRICS CASE STUDY

Metric	Estimate
Real Internal Rate of Return	35%
Benefit-to-Cost Ratio	7 to 1
Net Present Value using 1999 as the base year in year 2000 dollars	$8.8 million
Net Present Value using 2002 as the base year in year 2000 dollars	$10.8 million

The metrics for this particular case are necessarily based on a lower bound for expected benefits.[19] Even using the lower bound, the project was successful from an economic perspective. The internal rate of return is 35 percent, the benefit-to-cost ratio is 7 to 1, and the net present value in 2002 using in year 2000 dollars is $10.8 million.

Notes

1. This background information came from a face-to-face interview with Dr. Obrzut on October 23, 2001 at NIST and from subsequent correspondence. The technical definitions came from the on-line version of the *McGraw-Hill Encyclopedia of Science & Technology*, accessed through the Dartmouth College Information System.

2. Dielectric material, also known as dielectric, is a material that is an electrical insulator or in which an electric field can be sustained with a minimum dissipation of power. Dielectric film is a film possessing dielectric properties; it is used as the central layer of a capacitor.

3. The embedded capacitance is capacitance placed within the board rather than being attached to its exterior surface. Capacitance is the ratio of the charge on one of the conductors of a capacitor (there being an equal and opposite charge on the other conductor) to the potential difference between the conductors. A capacitor is a device that consists essentially of two conductors (such as parallel metal plates) insulated from each other by a dielectric and that introduces capacitance into a circuit, stores electrical energy, blocks the flow of direct current, and permits the flow of alternating current to a degree dependent on the capacitor's capacitance and the current frequency.

4. Dielectric constant is also known as relative dielectric constant, relative permittivity, and specific inductive capacity. For an isotropic (having identical properties in all directions) medium, dielectric constant is the ratio of the capacitance of a capacitor filled with a given dielectric to that of the same capacitor having only a vacuum as dielectric. Units are rationalized meter-kilogram-second units or centimeter-gram-second electrostatic units. Permittivity is the dielectric constant multiplied by the permittivity of empty space, where the permittivity of empty space is a constant appearing in Coulomb's law and has value of 1 in centimeter-gram-second electrostatic units and value of 8.854×10^{-12} farad/meter in rationalized meter-kilogram-second units.

5. Electrical impedance, also known as complex impedance, is the total opposition that a circuit presents to an alternating current, equal to the complex ratio of the voltage to the current in complex notation.

6. Toward successfully meeting these objectives, the project achieved four technical milestones. First, the research developed a prototype microwave test fixture for dielectric permittivity measurements of films using the APC-7 coaxial test port configuration. APC-7 is the Hewlett-Packard (HP) set-up standard; it is good up to high frequencies and provided NIST with the best configuration to work with given the objectives of the research. Second, the research developed computing algorithms suitable for quickly measuring impedance characteristics and transient charging of embedded decoupling capacitors. Third, the research analyzed the high-frequency relaxation process—that has been discovered in high dielectric constant composites—by investigating relaxation behavior of model polymer matrices filled with ferroelectric powders. And fourth, the research led to presentations and publications of the results to reach appropriate audiences.

7. Dielectric loss, also known as dielectric absorption, is the electric energy that is converted into heat in a dielectric subjected to a varying electric field.

8. The ATP intramural project enabled the team to focus on industry's needs as those needs were identified in the ATP Microelectronics Manufacturing Infrastructure Focused Program. For a description of that program, see: http://www.atp.nist.gov/atp/focus/micro.htm.

9. The publications, conference presentations, and research accomplishments associated with this project are in Appendix D.

10. A microwave is an electromagnetic wave that has a wavelength between about 0.3 and 30 centimeters, corresponding to frequencies of 1 to 100 gigahertz.

11. The data developed for discussion of the outcomes in this case study are based on discussions with Dr. Obrzut at NIST and interviews of several respondents in industry. Special thanks for their time and insights are due to respondents from StorageTek, Merix, DuPont, NCMS, 3M, Nortel, Gould Electronics, Oak-Mitsui, and Coretec.

12. Paraphrasing one respondent: There are other tests than Dr. Obrzut's that are available, but they do not properly characterize the thin dielectric materials. Dr. Obrzut's test does properly characterize them.

13. Paraphrasing the observations of another respondent: Dr. Obrzut's test method is a good method for the materials suppliers to allow them to do standardized tests and have understanding of the properties of their dielectric materials. The test method is not directly applicable to OEMs because the materials are already laminated into the printed circuit board by the time the OEMs get them. The test will be useful for the board fabricators to verify what they are getting from the materials suppliers. The test is being documented as an IPC standard.

14. Asked about the importance of Dr. Obrzut's test, a respondent with an OEM replied: "Without Dr. Obrzut's test it would be like going down the freeway without visual. If I ask for a certain dielectric constant, then I expect that to be built into the board when it gets to me. Dr. Obrzut's test will allow characterization using a small sample of material and a small sample preparation effort. Without his test, we would not have full knowledge about the material."

15. One respondent observed: "The production/failure costs avoided (increased yields realized) are of course down the road since the embedded capacitance is now only in prototypes. But the printed wiring board manufacturers would have reduced costs because of scrap avoided. In planning a new introduction, when figuring price they figure a factor for anticipated scrap."

An observer of the industry who has been actively involved in the development of embedded passive devices technology observed: "Such savings are going to be there down the road, and already as the materials manufacturers deal with the OEMs making prototypes such savings may be realized."

Another respondent observed: "Without the NIST testing methods, when an OEM found that a board did not behave as expected, a three-way battle would develop among materials suppliers, board fabricators, and OEMs. An OEM could refuse to accept a board."

A materials supplier was asked: Now, you do have these new materials, and they are in a small number of test vehicles. Regarding that development of new materials that you have at the moment, what would have happened at your company absent the NIST research outputs? The materials supplier responded: "We would have just continued to charge ahead making the materials. We would have relied on the OEMs to tell us if the materials were behaving properly in the applications. If they had not behaved as expected, we might have thought the problems were design specific. There would have been a lack of ability to really understand the materials' performance. In sum, we would have made the materials anyway, and then relied on the OEMs for performance evaluations." The materials supplier was then asked: Can you put a cost on that; can you quantify the benefits of having the new test metrology in terms of reduced problems of dealing with the OEM and board manufacturers? The response: "No, not yet, because the test is not yet routinely used sufficiently to have data yet. The vision of how it will be beneficial is correct, but we do not yet have dollar benefit data on the actual effects."

16. Paraphrasing the observations of one respondent: The greater flow of communications output enabled by the new embedded capacitance is of course still down the road since only prototypes currently exist of the embedded capacitance. The downturn in the industry has hurt the advancement of implementation of the technology. The larger OEMs would of course be looking at the embedding of capacitance in prototypes, trying to understand the behavior of embedded capacitance. But the design tools needed to put the material into the components are not yet in place. So designers if using the dielectric materials must force-feed the materials through the design process.

Paraphrasing the observations of another respondent, a board fabricator: The benefits of the NIST research output have not really flowed down to us yet. The development of the new standards are underway. The benefit of the NIST research will be the ability to make accurate measurements; i.e., the ability to say, "Make me a material that meets these properties using this test." We'll be buying materials from sources that are required to test in a certain way. As a fabricator, we will have the ability to process these new materials and put them into products for OEMs. The AEPT Consortium [the NCMS Advanced Embedded Passives Technology Consortium] is working to commercialize the new products. The embedded capacitance technology will enable new products. An OEM in the consortium believes that as the specification requirements for performance increase, the thin-film embedded capacitance approach is the only way to meet the new requirements. Cost is not the issue, but performance. Some of the work the consortium has done suggests that with embedded resistors and capacitors a 30 percent reduction in board size is possible.

17. The estimate for the in-kind contribution from industry was reported by a knowledgeable person from industry who was actively involved with Dr. Obrzut's project as a key representative from industry in the EDC consortium. To make the estimate, the reporting individual discussed the in-kind investments with other prominent, key individuals in industry who had knowledge of Dr. Obrzut's project, and together they reached the figure of $1,345,000.

18. One respondent observed: "We are working hard to commercialize the technology. We expect a commercial product—a material—in one year. We are less than a year from saying we have a commercial product. And, we are working with OEMs to explore the applications of the material. The new product must be sold to OEMs, designers, and fabricators. All of the AEPT consortium's work is aimed at accelerating the commercial application of embedded passive technology. The Obrzut/NIST test method is a subset of the overall effort."

19. As explained, the benefit stream used for the metrics is a lower bound for what expected profits would have been to support the investment. Changes in market conditions that were not anticipated at the time of the investments delayed the development and commercial application of embedded passive technology. With the passage of time and the emergence of the actual electronics applications of embedded capacitance in printed wiring boards, the impact of the ATP intramural funded dielectrics project is expected to be substantial.

8 Conclusions

This first evaluation of ATP's intramural research program has provided information about the inputs, outputs, outcomes, and impacts of the program. Survey information from principal investigators confirmed that outputs and outcomes from their research projects could be collected and used to describe the impact of ATP funding on the PI's research and his/her laboratory's research mission. Also, such descriptive information could be used to demonstrate knowledge spillovers that have resulted from the funded projects. From a broader perspective, the four case studies demonstrate clearly that there are significant economic benefits to industry associated with ATP's intramural funding. The case studies illustrate the types and magnitudes of benefits that industry is realizing because of the ATP intramural research program.

We recommend that ATP establish an evaluation program in which all funded PIs complete at the end of their project a survey form similar to the one used in this report to collect project information. In addition, we recommend that one or two case studies be conducted each year in an effort to develop a portfolio of case-based economic benefit data that could over time characterize the intramural program as a whole.

References

Bush, Vannevar. *Science—the Endless Frontier,* Washington, DC: U.S. Government Printing Office, 1945.

Council of Economic Advisers (CEA). *Economic Report of the President*, Washington, DC: U.S. Government Printing Office, February 2002.

Gilbert, Sarah L., and William C. Swann. Acetylene $^{12}C_2H_2$ Absorption Reference for 1510 nm to 1540 nm Wavelength Calibration—SRM 2517a, NIST Special Publication 260-133, 2001 Edition, Standard Reference Materials, Issued February 2001. Washington, DC: U.S. Government Printing Office, 2001.

Greene, William H. *LIMDEP Version 8.0* (within Nlogit 3.0, Version 3.02, November 26, 2002), Plainview, New York: Econometric Software, Inc., 2002.

Griliches, Zvi. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 1958, pp. 501–522.

Link, Albert N. "Economic Impact Assessments: Guidelines for Conducting and Interpreting Assessment Studies," NIST Planning Report 96-1, 1996a.

Link, Albert N. *Evaluating Public Sector Research and Development*, New York: Praeger Publishers, 1996b.

Link, Albert N., and John T. Scott. *Public Accountability: Evaluating Technology-Based Institutions*, Norwell, MA: Kluwer Academic Publishers, 1998.

Link, Albert N., and John T. Scott. "Public/Private Partnerships: Stimulating Competition in a Dynamic Economy," *International Journal of Industrial Organization*, 2001, pp. 763–794.

Mansfield, Edwin, John Rapoport, Anthony Romeo, Samuel Wagner, and George Beardsley. "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, 1977, pp. 221–240.

Office of Management and Budget (OMB). "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," Circular No. A-94, October 29, 1992.

Ruegg, Rosalie, and Irwin Feller. "A Toolkit for Evaluating Public R&D Investment Models, Methods, and Findings from ATP's First Decade," Gaithersburg, MD: NIST Report 03-857, July 2003.

StataCorp. "Stata Statistical Software: Release 7.0," College Station, TX: Stata Corporation, 2001.

Tassey, Gregory. "Methods for Assessing the Economic Impacts of Government R&D," Gaithersburg, MD: NIST Planning Report 03-01, 2003.

U.S. Census Bureau. *Statistical Abstract of the United States, 2001*, Washington, DC: U.S. Government Printing Office, 2002.

Appendices to the Report

APPENDIX A

Electronic Survey for All ATP Intramural Project PIs

The following statement prefaced the survey in the electronic communication with each PI.

Dear PI,

As you may know, the Office of Inspector General of the Department of Commerce has requested that the Economic Assessment Office of the Advanced Technology Program (ATP) conduct an economic evaluation of their intramural funding program.

John Scott (Dartmouth College) and I (University of North Carolina) have been asked by Jeanne Powell in the ATP office to undertake this project.

As part of our assignment, we have been instructed to survey all individuals who have received an ATP intramural research award. Attached to this email is a generic survey instrument (WORD document) approved by ATP.

As Linda Beth Schilling stated in her recent email to OU Directors about this survey: "Overall, we hope the results of this survey will help us know how to better collaborate with the laboratories using intramural funding. In addition, we expect statistics from this to be useful in summarizing some of the laboratories' achievements as a result of the funding—we would love to brag more about the results on our website to help with diffusing results to industry."

Would you please complete a separate survey instrument for each ATP intramural research project (just copy the instrument as many times as relevant). If there are co-researchers on an award, please respond from your perspective as PI. You may leave blank any questions that do not apply to your research. If your intramural research project was active in the early years of the program and you no longer have files on that project, feel free to return a blank instrument with a notation to that effect.

Our records show that you have received the following intramural research awards: [Name of award listed along with funding allocations by year]

Again, please fill out an instrument for each award. We would both appreciate receiving your completed forms within 2 weeks. Our email addresses are:

al_link@uncg.edu

john.t.scott@dartmouth.edu

In advance, thank you for your timely cooperation.

The survey instrument is:

ATP's intramural research award files show that you, as PI, have received funding from ATP for the project listed in the body of this email. If our facts are in error, we would appreciate you providing the correct information when you complete the shaded area of the instrument.

Please respond to the following questions, from your perspective as PI, within this WORD document. Please return your completed survey to us as an email attachment within 2 weeks: al_link@uncg.edu and john.t.scott@dartmouth.edu.

In advance, thank you.

	PROJECT TITLE
	Years and funding:
Q1	Did the scope of this intramural research project complement an ongoing research agenda in your laboratory, or did it help to initiate a new research direction—that is, did it expand NIST's competencies in new areas? Please explain.
Q2	Please provide complete bibliographic citations for all technical papers that resulted from this project and were published in professional journals, conference proceedings, or elsewhere.
Q3	Please provide complete citations for all patents filed or received that resulted from this project.
Q4	Approximately, how many professional presentations (outside of NIST) related to this project have been given? _____ And, to what types of groups?
Q5	Apart from publications, patents, and presentations, please list any other "technical outputs" that resulted from this project such as new measurement technology(ies), new standards, or new verified databases.

	PROJECT TITLE
Q6	Did this project contribute to the basis for subsequent NIST competency awards, other sources of federal funding to the laboratory, or CRADA activity? If so, please provide details.
Q7	Briefly, please offer your perception of the benefits that industry (please specify the industry(ies)) has received or will receive in the future from the results of this project.
Q8	If you have the names and phone numbers of individuals in industry with whom we may talk to learn more about the benefits that their industry has received or will receive in the future from the results of this project, please provide that information.
Q9	To conclude this survey, we would like to ask you to address these hypothetical questions. When making comparisons, please consider a hypothetical project with an amount of funding comparable to your ATP intramural project. If you had not received funding for this ATP intramural research project, would you have undertaken a project with <u>similar</u> goals and milestones? Yes ______ (please go to Q10) No ______ (please go to Q11)
Q10	As a result of ATP funding, are you *ahead/in the same place/behind* in achieving similar goals and milestones? ___________ If *ahead*, by approximately how many months? ______ How does this ATP intramural project compare to the project with <u>similar</u> goals and milestones that you would have undertaken without ATP funding (and we ask this question in an effort to characterize differences between projects with and without ATP funding and not to value one category of project over another)? Is it broader in scope? Yes/No ______ Is it more technically challenging? Yes/No ______ Is the expected duration/time to completion *longer/the same/shorter?* ______ Do you think that ATP funding led to *more/less/different* technical outputs (as listed below) compared to the technical outputs from the project you would have undertaken without ATP funding? Technical papers ______ Patents ______ New measurement technology ______ New standards ______ New databases ______ Please describe any other differences.

	PROJECT TITLE
Q11	Would you have undertaken a project in the same broadly defined research area as your ATP intramural project? Yes/No _____ If Yes, How does this ATP intramural project compare to that project (and we ask this question in an effort to characterize differences between projects with and without ATP funding and not to value one category of project over another)? Is it broader in scope? Yes/No _____ Is it more technically challenging? Yes/No _____ Is the expected duration/time to completion *longer/the same/shorter*? _____ Do you think that ATP funding led to *more/less/different* technical outputs (as listed below) compared to the technical outputs from the project you would have undertaken without ATP funding? Technical papers _____ Patents _____ New measurement technology _____ New standards _____ New databases _____ Please describe any other differences.

Again, thank you for your timely participation in this important study.

In terms of the framework of the study set forth earlier, the following outputs resulting from the intramural funding are considered within this survey: the scope of laboratory research (Q1), publications (Q2), patents (Q3), presentations (Q4), and other technical outputs (Q5). Additionally, outcomes are considered: leveraging of R&D funding (Q6 and Q9), cycle time of R&D (Q10), and the technical nature of R&D (Q11).

APPENDIX B

Quantitative Analysis of the PI Survey Results

Response Rates to the PI Survey

During the FY 1992 through FY 2000 period, ATP funded 1,052 intramural projects. Two hundred and seventy eight (278) PIs who were at NIST at the time of the study and were associated with 510 of these projects received electronic surveys.

Surveys were returned with at least some information for one or more projects by 43 percent of the 278 PIs; surveys were returned with at least some information for 41 percent of the 510 projects. Table B.1 summarizes the PI response rates by laboratory, and Table B.2 summarizes the project response rates by laboratory. In both tables, and in all tables that follow in this Appendix, laboratory 87 is retained as a separate laboratory although it was combined into laboratory 89 in 1997 and so reported above when summarizing budget allocations across laboratories. Of the 209 returned surveys, 30 reported that information

TABLE B.1. PI RESPONSE RATES TO THE SURVEY

Laboratory	Number of PIs	Response Rate (rounded %)
Electronics and Electrical Engineering (81)	40	38
Manufacturing Engineering (82)	38	58
Chemical Science and Technology (83)	54	32
Physics (84)	36	53
Material Science and Engineering (85)	57	40
Building and Fire Research (86)	13	38
Computer Systems (87)	11	45
Information Technology (89)	29	48
All	**278**	**43**

TABLE B.2. PROJECT RESPONSE RATES TO THE SURVEY

Laboratory	Number of Projects	Response Rate (rounded %)
Electronics and Electrical Engineering (81)	89	43
Manufacturing Engineering (82)	72	54
Chemical Science and Technology (83)	85	25
Physics (84)	68	49
Material Science and Engineering (85)	115	43
Building and Fire Research (86)	18	28
Computer Systems (87)	19	32
Information Technology (89)	44	41
All	**510**	**41**

was no longer available on the project; and thus, none of the survey questions was answered for those 30 projects. Table B.3 shows the overall response rates, by the year of project origination.

TABLE B.3. RESPONSE RATES BY YEAR OF PROJECT ORIGINATION (ROUNDED)

FY 1992	16 of 41 projects = 39.0%
FY 1993	15 of 40 projects = 37.5%
FY 1994	22 of 52 projects = 42.3%
FY 1995	30 of 66 projects = 45.5%
FY 1996	28 of 73 projects = 38.4%
FY 1997	19 of 52 projects = 36.5%
FY 1998	32 of 75 projects = 42.7%
FY 1999	29 of 65 projects = 44.6%
FY 2000	18 of 46 projects = 39.1%
All	**209 of 510 projects = 41%**

The response rate differed for some questions; therefore, a probability of response model was estimated for each individual question. The probability of response to a question is hypothesized to be a function of the difficulty of responding, the age of the project, the project's budget, and laboratory effects. The difficulty (*dif*) of responding for the PI is measured by the number of intramural research awards that the PI received.[1] The age (*age*) of the project is measured by the number of years since the project began. The total budget (*budget*) of the project is measured in constant 1996 dollars.[2] The laboratory (*lab81*, . . . , *lab89*) of the funded PI is also held constant in the model:

Probability of response = f (dif, age, budget, lab81, lab82, lab83, lab84, lab85, lab86, lab87, lab89)

When appropriate, the probit results from the probability of response model are provided throughout this appendix as each question is discussed.[3, 4]

The response models show that not all explanatory variables were important for response to all of the questions. However, for those questions where the explanatory variables for response were important, and controlling for the other variables that affect response, a PI was less likely to respond to a question for a particular project the greater the difficulty of responding and the greater the age of the project. In contrast, other things being controlled, response was more likely the larger the project's budget. The lab effects on the response probability, held constant in each response model, are at times significant as well.

PROJECT OUTPUTS AND OUTCOMES

Information was requested from each PI on broadly defined outputs and effects from each research project. These outputs included the effect on the scope of laboratory research, publications, citations, patents, presentations, and the leveraging effect on other funding sources. Each is discussed in order below.

Scope of Laboratory Research

Regarding the effect of intramural funding on the scope of laboratory research, each PI was asked about the relationship of the intramural project to ongoing research in the laboratory. As shown in Table B.4, 56.25 percent (n = 176)[5] of the projects initiated a new research direction, that is, they expanded NIST competencies in new areas, complementing an ongoing research agenda.

TABLE B.4. EFFECT OF ATP INTRAMURAL FUNDING ON THE SCOPE OF LABORATORY RESEARCH

Did the scope of this intramural research project complement an ongoing research agenda in your laboratory, or did it help to initiate a new research direction—that is, did it expand NIST's competencies in new areas?
Yes = 1, No = 0

Laboratory	Number of Projects	Initiate New Research Direction (rounded %)
Electronics and Electrical Engineering (81)	25	76
Manufacturing Engineering (82)	35	43
Chemical Science and Technology (83)	19	63
Physics (84)	29	55
Material Science and Engineering (85)	44	55
Building and Fire Research (86)	5	40
Computer Systems (87)	5	60
Information Technology (89)	14	57
All	**176**	**56**

Table B.5 shows the joint estimation of the probability of responding to the scope question and the probability of answering "yes" to the question. Estimating jointly the probability of response and the probability that scope increased shows that the correlation of the disturbances for the two equations is positive and indeed almost equal to 1.0. When the error in the response model is large and response is more likely to occur, then the error in the probit model for scope is also large and scope is more likely to have increased. For that reason, after controlling for the response bias in the results, the percentages in Table B.4 showing new research directions tend to be overestimates of the true probability that the laboratories' intramural projects increased the scope of the laboratory research.

Table B.6 shows the response-adjusted probabilities as predicted by the maximum likelihood estimates of the probit model for scope and the probit model from response.[6] The model's estimates are shown in Table B.5, and from that model the probability of a "yes" answer to the scope question is predicted for each observation in the complete 510 project

Appendices

TABLE B.5. PROBIT MODEL OF SCOPE WITH SAMPLE SELECTION*

Number of obs = 510; Censored obs = 334; Uncensored obs = 176;
Wald chi2(9) = 20.40; Prob > chi2 = 0.0156; Log likelihood = -419.99

Variable	Coefficient	Standard Error	z	P>|z|
Scope				
age	–.0636	.0299	–2.13	0.033
budget	1.44E-06	3.93E-07	3.67	0.000
lab82	–.1503	.2346	–0.64	0.522
lab83	–.3794	.2362	–1.61	0.108
lab84	.0150	.2290	0.07	0.948
lab85	–.1499	.2054	–0.73	0.466
lab86	–.4835	.4270	–1.13	0.257
lab87	–.0773	.3868	–0.20	0.842
lab89	–.2905	.2808	–1.03	0.301
constant	–.5794	.2367	–2.45	0.014
Select				
dif	–.0730	.0364	–2.00	0.045
age	–.0644	.0265	–2.43	0.015
budget	1.65E-06	3.99E-07	4.14	0.000
lab82	.4847	.2118	2.29	0.022
lab83	–.3150	.2169	–1.45	0.146
lab84	.3584	.2120	1.69	0.091
lab85	.1915	.1894	1.01	0.312
lab86	–.1358	.3525	–0.39	0.700
lab87	.0034	.3465	0.01	0.992
lab89	–.1509	.2567	–0.59	0.557
constant	–.2003	.2319	–0.86	0.388
athrho	4.5125	56.8739	0.08	0.937
rho	.9998	.0274		
LR test of indep. eqns. (rho = 0): chi2(1) = 3.07; Prob > chi2 = 0.0798				

* The results are for the joint maximum likelihood estimation of the probit model for scope and the response (selection) model for the 176 respondents that provided answers to the scope question. The statistic athrho is inverse hyperbolic tangent of rho the correlation between the disturbances in the probit model for scope and in the selection model for response to the scope question.

Note: Here and in the subsequent tables of Appendix B, E + nn or E – nn means multiply by 10 to + or – nn power.

TABLE B.6. PREDICTED EFFECT OF ATP INTRAMURAL FUNDING ON THE SCOPE OF LABORATORY

The probability that the intramural research project initiated a new research direction as predicted by the model reported in Table B.5: average of the probabilities predicted for each project in the categories shown.

Laboratory	Number of Projects	Probability Initiate New Research Direction (rounded %)
Electronics and Electrical Engineering (81)	89	22
Manufacturing Engineering (82)	72	21
Chemical Science and Technology (83)	85	14
Physics (84)	68	24
Material Science and Engineering (85)	115	20
Building and Fire Research (86)	18	12
Computer Systems (87)	19	17
Information Technology (89)	44	19
All	**510**	**20**

sample.[7] The predictions are averaged for each laboratory to get the results shown in Table B.6. On average, 20 percent of the projects are perceived to have an increase in scope (last row and column of Table B.6). Perhaps reflecting the 1997 ATP policy shift of intramural funding emphasis to generic projects that could cut across a group of ATP projects, older projects are less likely to be perceived as increasing the scope of the laboratory's research.

Publications

Information was requested on the number of publications, either in print or accepted for publication and forthcoming, which resulted directly from each project. Of the 179 projects, the mean number of publications per project was 5.01; the range was 0 to 62 as shown in Table B.7.[8] Also shown in Table B.7 are the mean and range by laboratory.

TABLE B.7. PUBLICATIONS PER PROJECT RESULTING FROM ATP INTRAMURAL PROJECTS

Please provide complete bibliographic citations for all technical papers that resulted from this project and were published in professional journal, conference proceedings, or elsewhere.

Laboratory	Number of Projects	Mean Number of Publications (rounded)	Range of Publications
Electronics and Electrical Engineering (81)	25	4.0	0–11
Manufacturing Engineering (82)	35	3.7	1–17
Chemical Science and Technology (83)	19	6.7	0–61
Physics (84)	28	4.3	0–18
Material Science and Engineering (85)	47	7.8	0–62
Building and Fire Research (86)	5	1.8	0–4
Computer Systems (87)	5	1.6	0–5
Information Technology (89)	15	2.3	0–7
All	**179**	**5.0**	**0–62**

The probit model for response to the question about publications is in Table B.8, and the results show that the probability of responding decreases with difficulty and with age, but increases with budget. The model shown in Table B.8 is also exactly the probit model for response to the questions about citations and about patents, because the respondents to all three questions were the same. Citations and patents are discussed subsequently.

TABLE B.8. PROBIT MODEL FOR RESPONSE TO THE PUBLICATIONS QUESTION

Binomial Probit Model. Maximum Likelihood Estimates

Dependent variable is the qualitative variable indicating response to the publications question: RPUB = 1 when the question was answered and = 0 otherwise.

Number of observations = 510; Log likelihood function = –310.9411; Restricted log likelihood = –330.5062;
Chi squared = 39.1303; Degrees of freedom = 10; Prob[ChiSqd > value] = .00002409;
Measures of Fit: Estrella = .07604; McFadden = .05920. Results retained for SELECTION model.

Variable	Coefficient	Standard Error	b/St.Er	P[|Z|>z]	Mean of X
Index function for probability					
constant	–2.3555	.7365	–3.198	.0014	
dif	–.7223E-01	.4397E-01	–1.643	.1004	2.5882
age	–.4449E-01	.2714E-01	–1.639	.1012	5.7510
ln(budget)	.1999	.5962E-01	3.353	.0008	11.4497
lab82	.5094	.2098	2.428	.0152	.1412
lab83	–.3268	.2177	–1.501	.1333	.1667
lab84	.3112	.2119	1.469	.1419	.1333
lab85	.2427	.1876	1.294	.1956	.2255
lab86	–.1646	.3544	–.464	.6424	.3529E-01
lab87	–.6721E-01	.3471	–.194	.8465	.3725E-01
lab89	–.7373E-01	.2533	–.291	.7710	.8627E-01

A complete negative binomial ("count") maximum likelihood regression model for the number of publications reported for each project can be readily estimated.[9] However, when estimated as a single equation, one does not know whether the effects of the explanatory variables on the estimated number of publications reflect true explanatory effects for the population of ATP projects, or instead reflect the association of the variables with the probability of response which is then in turn associated with the number of publications. To address this problem, the negative binomial model for publications was estimated simultaneously with the probit model for selection into the sample (that is, the model for the probability of response to the question about publications).[10] It is for some models very difficult to get maximum likelihood estimates of the response model and the count model of publications to converge; indeed, convergence and hence the estimates are available only for a very parsimonious count model for publications. That parsimonious model, estimated simultaneously with the full response model, is the only model of publications that is of interest or importance for this report. That is because we have the descriptive statistics for the reported publications as shown in Table B.7. A fully specified single-equation negative binomial count model provides a good fit to those data for the 179 projects that responded, but we do not care about that model because it confounds response effects with the effects of underlying explanatory variables. If we want to have the descriptive statistics for the 179 reporting projects, we have Table B.7, while if we want to estimate what the publications were for an ATP intramural project in the population, we need to use the best model that is estimable simultaneously with the model for response.

With correction for selection into the sample, Table B.9 shows the negative binomial count model for publications that could be estimated with the data available for the sample of ATP intramural projects. The estimated number of publications increases with the natural logarithm of the budget, and laboratory 82 is expected to have fewer publications holding constant the effect of the budget (the model actually predicts slightly higher publications per project for the 72 projects in laboratory 82 once the effect of budget size is controlled). Simultaneously estimated with the negative binomial count model, the individual coefficients in the model of response are no longer significant, but they are in themselves not of interest to us. The maximum likelihood correlation coefficient between the error in the probit model of response and in the count model is almost 1.0. From the estimated coefficients in the negative binomial model as corrected for sample selection, we have the predicted number of publications for a project equal to:

$$e^{-10.58 + 0.8635 ln(budget) - 0.1590 lab82}$$

Following this formulation, Table B.10 uses the negative binomial model (eliminating the selection effect) to predict the number of publications for each of the 510 projects in the

TABLE B.9. NEGATIVE BINOMIAL REGRESSION MODEL FOR THE NUMBER OF PUBLICATIONS FROM A PROJECT WITH CORRECTION FOR SAMPLE SELECTION

Number of observations = 510; Log likelihood function = –746.3022; Restricted log likelihood = –1210.219;
Chi squared = 927.8335; Degrees of freedom = 2; Prob[ChiSqd > value] = .0000000;
Mean of LHS Variable = 5.00559; Restr. Log–L is Poisson + Probit (indep); Log L for initial probit = –310.9411;
Log L for initial Poisson = –899.2779; Means for Psn/Neg.Bin. use selected data.

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Parameters of Poisson/Neg. Binomial Probability					
constant	–10.5813	1.4514	–7.290	.0000	
ln(budget)	.8635	.1126	7.671	.0000	11.6859
lab82	–.1590	.2735	–.581	.5611	.1955
Overdispersion Parameter for Negative Binomial					
theta	.2272	.1215	1.870	.0615	
Standard Deviation of Heterogeneity					
sigma	1.5611	.2014	7.753	.0000	
Correlation of Heterogeneity & Selection					
rho	.9999999994	.6184	1.617	.1058	

TABLE B.10. PREDICTED PUBLICATIONS PER PROJECT RESULTING FROM ATP INTRAMURAL PROJECTS

Laboratory	Number of Projects	Mean Number of Publications (rounded)	Range of Publications (rounded)
Manufacturing Engineering (82)	72	0.7	0.05–4.9
All except Manufacturing Engineering (82)	438	0.7	0.3–6.7
All	**510**	**0.7**	**0.3–6.7**

complete sample. Table B.10 shows the average predictions which, because of the elimination of the selection bias, show fewer predicted publications as compared to the actual numbers of publications per project for those responding to the survey. The model's prediction is that on average for all of the 510 projects, there were about two publications for every three projects (0.69 publications per project), rather than five publications per project as suggested by the respondents to the survey. To provide an indication of the robustness of the prediction here, we also estimated the negative binomial model with control for sample selection by using a two-step method directly analogous to the well-known model of Heckman. The model as we estimated it does not face the difficulties of obtaining convergence that occur with the full information maximum likelihood estimation of the selection and count models simultaneously. As a result, all of the explanatory variables other than the identifying variable, *dif*, could be included in the count model. Instead of predicting 0.69 publications per project, the two-step model predicts 0.65 publications per project—essentially the same answer of about two publications for every three projects.[11] However, our alternative approach is less orthodox than the formal approach using Greene's full information maximum likelihood approach, and we present only those results here.

Citations

The number of citations of each in-print publication was calculated on the basis of information in the Expanded Science Citation Index, as accessed through the Web of Science. Each publication that a PI reported on his/her returned survey was verified in the Expanded Science Citation Index and the number of non-self (including all co-authors) citations was counted. The mean (n = 133) number of non-self citations per publication for those projects reporting publications was 1.66; the range was 0 to 33. See Table B.11.

TABLE B.11. CITATIONS PER IN-PRINT PUBLICATION RESULTING FROM ATP INTRAMURAL PROJECTS

Laboratory	Number of Projects	Mean Number of Citations (rounded)	Range of Citations (rounded)
Electronics and Electrical Engineering (81)	18	0.2	1–1.3
Manufacturing Engineering (82)	23	0.1	0–1.6
Chemical Science and Technology (83)	15	1.2	0–4.6
Physics (84)	21	5.2	0–33
Material Science and Engineering (85)	39	2.3	0–32.7
Building and Fire Research (86)	3	0	—
Computer Systems (87)	3	0.2	0–0.5
Information Technology (89)	11	0.1	0–0.5
All	**133**	**1.7**	**0–33**

The probit model for response to the citations question is identical to the model for response in Table B.8, because the respondents to the two questions were the same. Table B.12 shows the negative binomial model for the counts of citations per project with correction for sample selection. The procedure used is the same as described in the section about the count model of publications.

The model was used to predict the number of citations for each of the 510 projects, and taking that prediction and then dividing by the number of publications for each project, Table B.13 shows the average predictions per publication for the typical project with the characteristics of the 133 projects reporting publications. The predicted number of citations per project is:

$$e^{-11.18 + 0.4695 age + 0.4560 ln(budget) + 3.40 lab83 + 3.96 lab84 + 2.43 lab85}$$

TABLE B.12. NEGATIVE BINOMIAL REGRESSION MODEL FOR THE NUMBER OF CITATIONS PER PROJECT WITH CORRECTION FOR SAMPLE SELECTION

Maximum Likelihood Estimates
Dependent variable = CITATION; Number of observations = 510; Log likelihood function = –633.5072;
Restricted log likelihood = –2713.536; Chi squared = 4160.058; Degrees of freedom = 2;
Prob[ChiSqd > value] = .0000000; Mean of LHS Variable = 10.29050; Restr. Log–L is Poisson+Probit (indep).
Log L for initial probit = –310.9411; Log L for initial Poisson = –2402.5950; Means for Psn/Neg.Bin. use selected data.

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Parameters of Poisson/Neg. Binomial Probability					
constant	–11.1785	1.5215	–7.347	.0000	
age	.4695	.5978E-01	7.854	.0000	5.4022
ln(budget)	.4560	.1062	4.292	.0000	11.6859
lab83	3.4042	.4749	7.169	.0000	.1061
lab84	3.9578	.4772	8.294	.0000	.1564
lab85	2.4298	.4204	5.780	.0000	.2626
Parameters of Probit Selection Model					
constant	–2.3697	.7311	–3.241	.0012	
dif	–.7404E-01	.5028E-01	–1.473	.1409	2.5882
age	–.4296E-01	.2898E-01	–1.482	.1383	5.7510
ln(budget)	.2001	.5943E-01	3.367	.0008	11.4497
lab82	.5248	.2119	2.477	.0133	.1412
lab83	–.3151	.2317	–1.360	.1739	.1667
lab84	.3240	.2125	1.525	.1273	.1333
lab85	.2433	.1885	1.291	.1969	.2255
lab86	–.1455	.3511	–.414	.6786	.3529E-01
lab87	–.5030E-01	.3488	–.144	.8853	.3725E-01
lab89	–.6848E-01	.2595	–.264	.7919	.8627E-01
Overdispersion Parameter for Negative Binomial					
theta	.8947E-01	.3696E-01	2.421	.0155	
Standard Deviation of Heterogeneity					
sigma	2.1222	.1493	14.214	.0000	
Correlation of Heterogeneity & Selection					
rho	.1249	.1456	.858	.3907	

Appendices

TABLE B.13. PREDICTED CITATIONS PER PREDICTED PUBLICATION FROM ATP INTRAMURAL PROJECTS, WITH CORRECTION FOR SELECTION, FOR THE 133 PROJECTS REPORTING AT LEAST ONE PUBLICATION*

Laboratory	Number of Projects	Mean Number of Citations per Publication (rounded)	Range of Citations per Publication (rounded)
All	133	1.8	0.01–22.9

*The count model for publications with correction for sample selection predicts an average of 1.00 publication for the 133 projects for which actual publications were 5.01 per project (Table B.7). The error in the selection model was highly correlated with the error in the publications count model, so the 133 reporting projects had more publications than expected for the typical projects with their characteristics. The count model for citations with correction for sample selection predicts an average of 1.48 citations for the 133 projects. The ratio of the predicted citations to the predicted publications averaged across the 133 projects is 1.76. The reporting projects had more publications than expected for the typical project and somewhat more citations; the ratio, or citations per publication, for the typical project with publications is essentially the same as for the 133 reporting projects.

For all projects having publications, the average number of citations is predicted to be about the same as the one and two-thirds citations per publication for the responding projects. Typical projects would have fewer publications and fewer citations, but the citations per publication would be about the same as for the reporting projects.

Patents

Patenting is not an integral part of the research mission of NIST scientists. However, a few PIs for selected projects did report that a patent had either been filed or had been received. As shown in Table B.14, on average (n = 179), the number of patents per project was 0.05 with a range of 0 to 3. Disaggregation of the survey data by laboratory is not meaningful for this output measure because so few patents had been filed or received; for the same reason, estimating a count model for patents is not sensible.

TABLE B.14. PATENTS PER PROJECT FROM THE ATP INTRAMURAL PROJECTS

Laboratory	Number of Projects Reporting	Mean Number of Patents (rounded)	Range of Patents
All	179	0.05	0–3

Presentations

Presentations are the primary mode for quickly and effectively disseminating information from NIST research. On average (n = 174), the number of presentations per project was 9.55 with a range of 0 to 150. See Table B.15.

TABLE B.15. PRESENTATIONS PER PROJECT RESULTING FROM ATP INTRAMURAL PROJECTS

Approximately, how many professional presentations (outside of NIST) related to this project have been given?

Laboratory	Number of Projects	Mean Number of Presentations (rounded)	Range of Presentations
Electronics and Electrical Engineering (81)	25	4.2	0–15
Manufacturing Engineering (82)	34	7.9	0–60
Chemical Science and Technology (83)	19	17.3	0–150
Physics (84)	28	7.6	0–40
Material Science and Engineering (85)	43	15.4	0–150
Building and Fire Research (86)	5	3.4	0–10
Computer Systems (87)	5	2.6	0–10
Information Technology (89)	15	3.4	0–9
All	**174**	**9.6**	**0–150**

The probit model for response to the presentations question is shown in Table B.16. Table B.17 shows the negative binomial model estimated simultaneously with the model for response following the procedure introduced to model publications above. The model was used to predict the number of presentations for each of the 510 projects as the base to the natural logarithms raised to the power:

$$-11.32 + .9177\, ln(budget) + .5885\, lab82 + .5774\, lab83 + 1.007\, lab84 + .1414\, lab85 + .1303\, lab86 - 1.013\, lab87 + .3731\, lab89$$

TABLE B.16. PROBIT MODEL OF RESPONSE TO PRESENTATIONS QUESTION

Binomial Probit Model; Maximum Likelihood Estimates

Dependent variable, RPRES, equals 1 if the project was one of the 174 that responded to the presentations question and equals zero otherwise.

Number of observations = 510; Log likelihood function = –307.9056; Restricted log likelihood = –327.3245;
Chi squared = 38.8378; Degrees of freedom = 10; Prob[ChiSqd > value] = .2710E-04;
Fit Measures: Estrella = 0.07550; McFadden = 0.05933;
Results retained for SELECTION model.

Variable	Coefficient	Standard Error	b/St.Er	P[|Z|>z]	Mean of X
Index function for probability					
constant	–2.2814	.7388	–3.088	.0020	
dif	–.9528E-01	.4459E-01	–2.137	.0326	2.5882
age	–.4515E-01	.2721E-01	–1.659	.0971	5.7510
ln(budget)	.2000	.5993E-01	3.337	.0008	11.4497
lab82	.4639	.2099	2.210	.0271	.1412
lab83	–.3531	.2180	–1.620	.1053	.1667
lab84	.3026	.2120	1.427	.1535	.1333
lab85	.1392	.1889	.737	.4613	.2255
lab86	–.1956	.3550	–.551	.5816	.3529E-01
lab87	–.8796E-01	.3479	–.253	.8004	.3725E-01
lab89	–.1013	.2539	–.399	.6898	.8627E-01

TABLE B.17. NEGATIVE BINOMIAL REGRESSION MODEL FOR THE NUMBER OF PRESENTATIONS PER PROJECT WITH CORRECTION FOR SAMPLE SELECTION

Maximum Likelihood Estimates
Dependent variable = PRES; Number of observations = 510; Log likelihood function = –795.8038;
Restricted log likelihood = –2030.521; Chi squared = 2469.434; Degrees of freedom = 2;
Prob[ChiSqd > value] = .0000000; Mean of LHS Variable = 9.5345;
Restr. Log-L is Poisson+Probit (indep).; Log L for initial probit = –307.9056;
Log L for initial Poisson = –1722.6152; Means for Psn/Neg.Bin. use selected data.

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Parameters of Poisson/Neg. Binomial Probability					
constant	–11.3196	.8405	–13.467	.0000	
ln(budget)	.9177	.6440E-01	14.251	.0000	11.6872
lab82	.5885	.2192	2.684	.0073	.1954
lab83	.5774	.2163	2.669	.0076	.1092
lab84	1.0069	.2592	3.884	.0001	.1609
lab85	.1414	.2058	.687	.4921	.2471
lab86	.1303	.4035	.323	.7467	.2874E-01
lab87	–1.0129	.9033	–1.121	.2622	.2874E-01
lab89	.3731	.3363	1.109	.2674	.8621E-01
Overdispersion Parameter for Negative Binomial					
theta	.5007E-01	.1794E-01	2.791	.0053	
Standard Deviation of Heterogeneity					
sigma	1.6187	.7094E-01	22.818	.0000	
Correlation of Heterogeneity & Selection					
rho	.9999999998	.1166	8.574	.0000	

Table B.18 shows the average prediction per project for each laboratory after correcting for the response effect. About one presentation per project is expected on average for all 510 projects, rather than almost 10 presentations per project for those responding to the survey. Again, it is worth noting that the result is the same result we obtained initially using a two-step estimator analogous to Heckman's estimator. That model predicted 0.90 presentations per project as compared to the prediction here of 1.01—essentially one presentation per project.

TABLE B.18. PREDICTED PRESENTATIONS PER PROJECT RESULTING FROM ATP INTRAMURAL PROJECTS

Laboratory	Number of Projects	Mean Number of Presentations (rounded)	Range of Presentations (rounded)
All	510	1	0.02–10.6

Leveraging Additional Funding

In addition to the knowledge spillovers associated with publications, citations, and presentations, the ATP intramural projects also leveraged other sources of funding such as NIST competency awards or CRADA activity. For the responding projects (n = 176), 30.68 percent of the projects leveraged additional funding as shown in Table B.19.

TABLE B.19. IMPACT OF ATP INTRAMURAL PROJECT ON LEVERAGING OTHER SOURCES OF FUNDING

Did this project contribute to the basis for subsequent NIST competency awards, other sources of federal funding to the laboratory, or CRADA activity? Yes = 1, No = 0

Laboratory	Number of Projects	Leveraging Rate (rounded %)
Electronics and Electrical Engineering (81)	25	24
Manufacturing Engineering (82)	35	20
Chemical Science and Technology (83)	18	39
Physics (84)	27	44
Material Science and Engineering (85)	47	34
Building and Fire Research (86)	5	20
Computer Systems (87)	5	20
Information Technology (89)	14	29
All	**176**	**31**

Table B.20 presents the maximum likelihood estimation of the probit model with sample selection.[12] Although the model of selection (response) is quite significant and tells the same story we have already seen about response, there are not significant differences across the labs in the probability of leveraging subsequent competency awards. The differences not being significant, we report for the 510 projects in the complete sample simply the average prediction of that probability for a project. That average probability is 0.14 and the range across the 510 projects for the predicted probability of leveraging is from 0.02 to 0.37. However, we cannot reject the possibility that the selection and leveraging models are independent, and so perhaps the estimates from our respondents in Table B.19 are the best ones.

TABLE B.20. PROBIT MODEL OF LEVERAGING COMPETENCY AWARDS OR SIMILAR FUNDED AWARDS WITH SAMPLE SELECTION

Number of obs = 510; Censored obs = 334; Uncensored obs = 176;
Wald chi2(9) = 12.66; Prob > chi2 = 0.1788; Log likelihood = –407.6357

Variable	Coefficient	Standard Error	Z	P>|z|
compet				
age	.0382	.0600	0.64	0.524
ln(budget)	.2448	.1021	2.40	0.017
lab82	–.0018	.3903	–0.00	0.996
lab83	.1585	.4583	0.35	0.729
lab84	.4983	.3429	1.45	0.146
lab85	.3291	.3013	1.09	0.275
lab86	–.1419	.6127	–0.23	0.817
lab87	–.3292	.6559	–0.50	0.616
lab89	.1645	.4259	0.39	0.699
constant	–4.3372	1.3162	–3.30	0.001
select				
dif	–.0636	.0431	–1.48	0.140
age	–.0663	.0270	–2.45	0.014
budget	1.60E-06	4.01E-07	3.98	0.000
lab82	.4850	.2129	2.28	0.023
lab83	–.3567	.2214	–1.61	0.107
lab84	.2831	.2150	1.32	0.188
lab85	.2592	.1892	1.37	0.171
lab86	–.1488	.3539	–0.42	0.674
lab87	.0151	.3485	0.04	0.965
lab89	–.1433	.2568	–0.56	0.577
constant	–.2059	.2388	–0.86	0.389
athrho	.7822	1.0993	0.71	0.477
rho	.6540	.6292		

LR test of indep. eqns. (rho = 0): chi2(1) = 0.68: Prob > chi2 = 0.4107

NIST BENCHMARKS

To place these outputs and impacts in perspective, ATP provided selected NIST-wide benchmark data. As shown in Table B.21, the performance of the ATP-funded projects that reported their publications in response to the survey had a much higher number of publications per million dollars of budget (in constant 1996 dollars) than the average project in the same NIST laboratory. The estimated models of response and of publications do suggest that the responding ATP-funded projects performed exceptionally well relative to all ATP intramural projects. If the predictions of the model of publications with control for selection effects were used instead of the actual performance of the ATP-funded projects

TABLE B.21. COMPARISON OF PUBLICATIONS FOR ATP INTRAMURAL AND NIST PROJECTS*

ATP Intramural Projects with Starting Dates from FY94 through FY00 and Respondents with Publications and Budget Data

Laboratory	n	Publications	Budget (year 1996 dollars, ($1,000s)	Publications per $million of Budget (rounded)
Electronic and Electrical Engineering (81)	24	93	2,983	31.2
Manufacturing Engineering (82)	29	100	7,015	14.3
Chemical Science and Technology (83)	17	67	4,223	15.9
Physics (84)	20	72	3,623	19.9
Material Science and Engineering (85)	44	352	6,613	53.2
Building and Fire Research (86)	4	9	644	14.0
Information Technology (89)	17	38	2,771	14.0

All NIST Laboratories from FY 1994 through FY 2000

Laboratory	Average Annual Publications	Average Annual Budget (year 1996 dollars, $1,000s)	Publications per $million of Budget (rounded)
Electronic and Electrical Engineering (81)	232	36,884	6.3
Manufacturing Engineering (82)	163	28,779	5.7
Chemical Science and Technology (83)	350	41,127	8.5
Physics (84)	276	29,920	9.2
Material Science and Engineering (85)	489	41,792	11.7
Building and Fire Research (86)	241	20,856	11.6
Information Technology (89)	197	40,703	4.8

* The 510 observation sample of ATP intramural projects includes projects as old as those beginning in FY 1992 (with age 2002–1992 = 10) and as young as those beginning in FY 2000 (with age 2002–2000 = 2). NIST provided budget data for each lab for FY 1994 through FY 2001, as well as publications data by lab for those years and the years before and FY 2002. To have comparable data, in the table we used (1) ATP projects between two and eight years old (the youngest starting in FY 2000 and the oldest starting in FY 1994), and (2) the NIST lab data for FY 1994 though FY 2000. As the estimated models (both the Greene approach and the *ad hoc* two-step approach) show, age is not a factor explaining publications in the sample where the youngest projects are two years old. For applied science and technology, the papers come fairly quickly. The publications and budgets for the ATP intramural projects are observed at the project level, and the matching is therefore exact. For the NIST lab performance, the publications and budget data are at the lab level. The appropriate lag between project funding and publications is not known, and furthermore the projects extend over multiple years with publications coming throughout the projects' lives. Examination of the annual publications and budget (in constant 1996 dollars) data suggest a stable, annual relation between publications and budget, so for the NIST performance results the average annual number of publications per million dollars of budget was used.

that responded to the survey, the predicted publications per million dollars of budget for the ATP intramural projects would not outperform the typical NIST projects. The predictions, however, are not the actual performance observed, but rather would be the best guess about the performance of an analogous, hypothetical project apart from random error. On average, the actual performance regarding publications for the reporting ATP intramural projects far exceeded the performance of the typical NIST laboratory projects.

HYPOTHETICAL EFFECTS OF INTRAMURAL FUNDING

In an effort to compare the nature of the intramural funded project to research activities that would have occurred in the absence of such funding, a number of hypothetical questions were asked.

Overall (n = 151), PIs reported that 46 percent of the projects would have been undertaken as a project with similar goals and milestones had ATP funding not been received. See Table B.22. However, these hypothetical projects, although with similar goals and milestones, would have taken longer to complete, would have been less technically challenging, and would have generated fewer technical outputs as noted below.

TABLE B.22. PROBABILITY OF UNDERTAKING A SIMILAR RESEARCH PROJECT ABSENT ATP INTRAMURAL FUNDING

If you had not received funding for this ATP intramural project, would you have undertaken a project with similar goals and milestones? Yes = 1, No = 0. When making this comparison, please consider a hypothetical project with an amount of funding comparable to your ATP intramural project.

Laboratory	Number of Projects	Probability (rounded %)
Electronics and Electrical Engineering (81)	20	40
Manufacturing Engineering (82)	30	50
Chemical Science and Technology (83)	16	44
Physics (84)	23	74
Material Science and Engineering (85)	42	45
Building and Fire Research (86)	3	33
Computer Systems (87)	3	0
Information Technology (89)	14	21
All	**151**	**46**

The probit model for undertaking similar projects absent ATP funding shows that neither project age nor project budget has a significant effect on the probability that a similar project will be undertaken. Table B.23 shows the appropriate probit model with control for selection into the sample. For completeness and to allow comparison with Table B.22, Table B.24 uses the model to predict the probability that similar projects will be undertaken. However, as Table B.23 shows, we cannot reject the hypothesis that the selection model is independent of the probit model regarding undertaking similar projects. Of course, the predicted probabilities in Table B.24 are higher than those observed without control for sample selection, because the error in the probit for response is negatively correlated with the

TABLE B.23. PROBIT MODEL FOR UNDERTAKING SIMILAR PROJECT ABSENT ATP FUNDING WITH SAMPLE SELECTION*

Probit model with sample selection
Number of obs = 491; Censored obs = 343; Uncensored obs = 148;
Wald chi2(8) = 9.74; Prob > chi2 = 0.2841; Log likelihood = –373.1646

Variable	Coefficient	Standard Error	z	P>|z|
absent				
age	.0363	.1318	0.28	0.783
budget	–1.11E-07	2.04E-06	–0.05	0.957
lab82	.0305	1.0092	0.03	0.976
lab83	.1297	.4068	0.32	0.750
lab84	.7105	1.2128	0.59	0.558
lab85	.0157	.7380	0.02	0.983
lab86	–.0174	.8894	–0.02	0.984
lab89	–.5022	.4946	–1.02	0.310
constant	.2074	2.3398	0.09	0.929
select				
dif	–.0475	.0500	–0.95	0.343
age	–.0810	.0288	–2.81	0.005
budget	1.61E-06	4.04E-07	3.98	0.000
lab82	.4632	.2291	2.02	0.043
lab83	–.2736	.2301	–1.19	0.234
lab84	.2919	.2208	1.32	0.186
lab85	.3024	.1994	1.52	0.129
lab86	–.3729	.3980	–0.94	0.349
lab89	.0171	.2610	0.07	0.948
constant	–.3381	.2484	–1.36	0.173
athrho	–.5433	2.5149	–0.22	0.829
rho	–.4955	1.8975		

LR test of indep. eqns. (rho = 0): chi2(1) = 0.03: Prob > chi2 = 0.8596

* The category lab87 predicts perfectly that there will be no such similar projects absent the ATP funding; it is therefore dropped from the model along with the 19 projects from lab87.

TABLE B.24. PREDICTED PROBABILITY OF UNDERTAKING A SIMILAR RESEARCH PROJECT ABSENT ATP INTRAMURAL FUNDING

Laboratory	Number of Projects	Probability (rounded)
Electronics and Electrical Engineering (81)	89	0.7
Manufacturing Engineering (82)	72	0.7
Chemical Science and Technology (83)	85	0.7
Physics (84)	68	0.9
Material Science and Engineering (85)	115	0.7
Building and Fire Research (86)	18	0.6
Computer Systems (87)	19	—
Information Technology (89)	44	0.4

error in the probit for undertaking similar projects absent ATP funding. If one accepts the correlation estimated, then when the error in the response equation is large and a project is likely to respond, the error in the probit for undertaking similar projects is small and the reported project is less likely to have undertaken a similar project without the ATP support. However, the correlation is not at all significant, and the results from our respondents in Table B.22 are the ones to use.

Table B.25 shows that as a result of ATP funding, 84 percent of the research that was conducted was ahead in achieving similar goals and milestones by an average of 12 months (n = 69).

TABLE B.25. EFFECT OF ATP INTRAMURAL FUNDING IN ACHIEVING SIMILAR GOALS AND MILESTONES

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

As a result of ATP funding, are you ahead/in the same place/behind in achieving similar goals and milestones? If ahead, by approximately how many months?

Laboratory	Number of Projects	Ahead (rounded %)	Months Ahead (rounded)	Same Place (rounded %)	Behind (rounded %)
Electronics and Electrical Engineering (81)	8	100	11	0	0
Manufacturing Engineering (82)	15	87	15	7	7
Chemical Science and Technology (83)	7	71	14	29	0
Physics (84)	17	100	10	0	0
Material Science and Engineering (85)	18	67	13	28	6
Building and Fire Research (86)	1	100	12	0	0
Computer Systems (87)	0	—	—	—	—
Information Technology (89)	3	67	9	33	0
All	**69**	**84**	**12**	**13**	**3**

Table B.26 shows the probit model for being ahead of schedule because of ATP funding (see Table B.25) with control for the response to the question. The model for being ahead could not be estimated with age included (there were numerical problems and the model would not converge). So, in Table B.26, just the budget enters the substantive equation (although age is included in the selection equation as usual). The key finding, if one trusted the model's results, would be that the probability of being ahead of schedule because of the ATP funding is essentially 1.0 for all labs, rather than being as low as two-thirds for some of the labs as indicated in the responses shown in Table B.25. The variance in the percentages of projects reporting that they are ahead would result because of the response bias—again, if we decide to trust the model here. Although the correlation in the disturbances of the response and the substantive model are strongly negative (estimated to be –1!), the standard error for the estimated correlation is very large. The test for the independence of the equations, however, shows that they are unlikely to be independent. In any case, whether one believes the predictions of the model, or simply takes the lower estimates reported in Table B.25, ATP intramural projects are quite likely to be ahead of schedule because of the ATP funding.

TABLE B.26. PROBIT MODEL WITH CONTROL FOR RESPONSE FOR BEING AHEAD OF SCHEDULE*

Probit model with sample selection
Number of obs = 316; Censored obs = 273; Uncensored obs = 43;
Wald chi2(4) = 11.71; Prob > chi2 = 0.0196; Log likelihood = –131.0742

Variable	Coef.	Std. Err.	z	P>|z|
Q10ahead				
ln(budget)	.2344	.0881	2.66	0.008
lab83	–.2341	.4009	–0.58	0.559
lab85	–.3676	.1388	–2.65	0.008
lab89	.1425	.4590	0.31	0.756
constant	–.7005	.7949	–0.88	0.378
select				
dif	–.0781	.0466	–1.68	0.093
age	–.0947	.0282	–3.37	0.001
budget	1.75E-06	4.10E-07	4.27	0.000
lab83	–.6585	.2573	–2.56	0.010
lab85	–.2012	.1892	–1.06	0.288
lab89	–.8691	.3413	–2.55	0.011
constant	–.4024	.2795	–1.44	0.150
athrho	–12.9267	313.9783	–0.04	0.967
rho	–1	7.43E-09		

LR test of indep. eqns. (rho = 0): chi2(1) = 4.08: Prob > chi2 = 0.0434

* For the model: The larger model analogous to the other estimated models (including age in the performance equation) would not converge. Examining just the performance equation suggests that age is not an important factor here, but in any case with the sample remaining for estimation (see note **), we cannot jointly estimate the larger model.

** Note that there are just 316 projects for the probit model with selection, because from the original 510 projects, the 89 projects from lab81, the 68 projects from lab84, and the 18 projects from lab 86 are dropped because they predict perfectly that the project is ahead of schedule, and the 19 projects from lab87 are dropped because there were no respondents to the hypothetical questions from lab87. (510 – 89 – 68 – 18 – 19 = 316).

To summarize the findings from the model: The probabilities for being ahead for projects in lab 81, lab 84, and lab 86 are estimated to be 1.0 given the perfect prediction for those labs. Lab 87 had no respondents to the hypothetical questions and hence we omit it from the estimated probabilities. Using the probit model with control for response to estimate the probability of being ahead for each project and then averaging the probabilities for projects in each lab, we find the probabilities for the remaining labs as shown in Table B.27. Accepting with caution the model as discussed in the preceding paragraph, then response bias is essentially the reason that labs 82, 83, 85, and 89 report, as seen in Table B.25, lower probability of being ahead. Essentially all the labs show for their ATP-funded projects a probability of being ahead that is very close to 1.0. The strong negative correlation in the disturbances in the response probit and the probit for being ahead of schedule resulted in the lower reported percentages for being ahead in labs 82, 83, 85, and 89.

TABLE B.27. PREDICTED PROBABILITY OF BEING AHEAD OF THE HYPOTHETICAL PROJECT

Laboratory	Number of Projects	Probability (rounded %)
Electronics and Electrical Engineering (81)	89	100
Manufacturing Engineering (82)	72	97
Chemical Science and Technology (83)	85	95
Physics (84)	68	100
Material Science and Engineering (85)	115	95
Building and Fire Research (86)	18	100
Computer Systems (87)	19	—
Information Technology (89)	44	98

Table B.25 shows as well the average number of months ahead of schedule for the projects in each lab reporting being ahead. The data for months ahead were examined with the Heckman model of regression with selection.[13] The selection model is reported in Table B.28, and it is used to predict the number of months ahead of schedule for the average proj-

TABLE B.28. MODEL FOR THE NUMBER OF MONTHS AHEAD OF SCHEDULE*

Heckman selection model (regression model with sample selection)
Number of obs = 491; Censored obs = 424; Uncensored obs = 67;
Wald chi2(7) = 19.90; Prob > chi2 = 0.0058; Log likelihood = –399.9063

Variable	Coefficient	Standard Error	z	P>|z|
Q10b				
ln(budget)	3.8107	1.0308	3.70	0.000
lab82	–1.5438	3.2050	–0.48	0.630
lab83	–4.5878	3.4157	–1.34	0.179
lab84	–4.5726	3.1102	–1.47	0.142
lab85	–4.6500	2.8586	–1.63	0.104
lab86	–1.2125	6.9311	–0.17	0.861
lab89	–2.8269	4.4121	–0.64	0.522
constant	–27.1367	16.2870	–1.67	0.096
select				
dif	.0127	.0553	0.23	0.819
age	–.0649	.0329	–1.98	0.048
budget	1.28E-06	3.66E-07	3.49	0.000
lab82	.4909	.2630	1.87	0.062
lab83	–.0935	.2879	–0.32	0.745
lab84	.5878	.2586	2.27	0.023
lab85	.2964	.2414	1.23	0.219
lab86	–.2721	.5322	–0.51	0.609
lab89	–.2575	.3558	–0.72	0.469
constant	–1.2033	.2995	–4.02	0.000
athrho	–.4780	.5253	–0.91	0.363
lnsigma	1.9320	.1960	9.86	0.000
rho	–.4447	.4214		
sigma	6.9033	1.3529		
lambda	–3.0696	3.4594		

LR test of indep. eqns. (rho = 0): chi2(1) = 0.57: Prob > chi2 = 0.4491

* The larger model, with age in the substantive equation for the number of months ahead, would not converge for this sample.

ect in each lab (excepting lab 87, which provided no responses for this question), and the results are shown in Table B.29. The errors for the response model and the model for the months ahead of schedule are negatively correlated; hence, the predicted number of months is greater than was suggested by the reported number in Table B.25. However, we cannot reject the null hypothesis of the independence of the errors. As usual, the response model shows that PIs for older projects were less likely to respond while those having projects with larger budgets were more likely to respond, but there is not a clear statistically significant response effect in the number of months ahead that are reported. For that reason, the most reliable information is probably simply the data for average months ahead as reported in Table B.25.

TABLE B.29. THE PREDICTED NUMBER OF MONTHS AHEAD OF SCHEDULE

Laboratory	Number of Projects	Average Months
Electronics and Electrical Engineering (81)	89	16
Manufacturing Engineering (82)	72	15
Chemical Science and Technology (83)	85	12
Physics (84)	68	12
Material Science and Engineering (85)	115	12
Building and Fire Research (86)	18	15
Computer Systems (87)	19	—
Information Technology (89)	44	14
All	**510 – 19 = 491**	**14**

Table B.30 shows that, on average (n = 69), 49 percent of the ATP intramural projects reported that they were broader in scope than the hypothetical projects. Again there is a negative correlation in the errors for the response probit and the probit for broader scope, resulting in greater response-corrected predictions for the probability of an ATP-supported project having broader scope. The correlation, while perfectly negative, is not significant,

TABLE B.30. SCOPE OF ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Is it broader in scope? Yes = 1, No = 0

Laboratory	Number of Projects	Broader in Scope (rounded %)
Electronics and Electrical Engineering (81)	8	63
Manufacturing Engineering (82)	15	53
Chemical Science and Technology (83)	7	86
Physics (84)	17	53
Material Science and Engineering (85)	18	28
Building and Fire Research (86)	1	0
Computer Systems (87)	0	—
Information Technology (89)	3	33
All	**69**	**49**

although the response and the scope equations do not appear to be independent. Table B.31 shows the probit model for broader scope with control for response. The observations for lab86 are dropped because they predict perfectly and the observations for lab87 are dropped because we have no respondents from lab87 for the hypothetical questions. For completeness, Table B.32 shows the probabilities for broader scope for the average project

TABLE B.31. PROBIT MODEL FOR BROADER SCOPE AS COMPARED WITH THE HYPOTHETICAL PROJECT AND WITH CONTROL FOR RESPONSE*

Probit model with sample selection
Number of obs* = 473; Censored obs = 405; Uncensored obs = 68
Wald chi2(5) = 15.43; Prob > chi2 = 0.0087; Log likelihood = –221.2145

Variable	Coefficient	Standard Error	z	P>|z|
Q10c				
lab82	–.6508	.3363	–1.94	0.053
lab83	.3218	.4652	0.69	0.489
lab84	–.5903	.3179	–1.86	0.063
lab85	–.6952	.2648	–2.63	0.009
lab89	–.0692	.4111	–0.17	0.866
constant	1.8552	.2535	7.32	0.000
select				
age	–.0523	.0131	–4.00	0.000
budget	1.11E-06	2.73E-07	4.09	0.000
lab82	.4616	.2557	1.81	0.071
lab83	–.1161	.2777	–0.42	0.676
lab84	.6990	.2503	2.79	0.005
lab85	.2686	.2047	1.31	0.190
lab89	–.2572	.3436	–0.75	0.454
constant	–1.1925	.1939	–6.15	0.000
athrho	–10.4403	130.7562	–0.08	0.936
rho	–1	4.47E-07		

LR test of indep. eqns. (rho = 0): chi2(1) = 3.90: Prob > chi2 = 0.0482

* The 18 observations for lab86 were dropped because they are predicted perfectly, and the observations for lab87 were dropped because we have no respondents from lab87 for the hypothetical questions. Thus the sample size is 510 – 18 – 19 = 473. For this sample, the larger model with age and budget in the substantive model and with age, budget, and dif in the selection model, could not be estimated (the estimation would not converge).

TABLE B.32. THE PREDICTED PROBABILITIES OF BROADER SCOPE AS COMPARED WITH THE HYPOTHETICAL PROJECT

Laboratory	Number of Projects	Probability (rounded %)
Electronics and Electrical Engineering (81)	89	100
Manufacturing Engineering (82)	72	90
Chemical Science and Technology (83)	85	99
Physics (84)	68	90
Material Science and Engineering (85)	115	88
Building and Fire Research (86)	18	100*
Computer Systems (87)	19	—
Information Technology (89)	44	96

* This prediction is based on a single observation and should therefore be discounted accordingly.

as predicted by the model, although given its uncertainties, the respondents' reports as summarized in Table B.30 are probably the best indication about scope relative to hypothetical projects.

Table B.33 shows that, on average (n = 66), 58 percent of the ATP intramural projects are more technically challenging than the hypothetical projects. The maximum likelihood probit model (with control for selection) for greater technical challenge shows that the correlation coefficient rho between the errors in the probit model for technical challenge and the probit model for response is not significantly different from zero. Further, the response model and the model of technical challenge are clearly independent of one another. As with the response to the other questions, response was more likely for projects with larger budgets, and response was less likely for the older projects. However, there is no response bias in the answers to this question, and the best model is simply the model shown in Table B.34 that uses the lab effects and then just the significant variables among the remaining explanatory variables. Table B.35 shows the predicted probabilities across the laboratories.

TABLE B.33. TECHNICAL CHALLENGE OF ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Is it more technically challenging? Yes = 1, No = 0

Laboratory	Number of Projects	More Technically Challenging (rounded %)
Electronics and Electrical Engineering (81)	8	75
Manufacturing Engineering (82)	15	73
Chemical Science and Technology (83)	6	67
Physics (84)	15	33
Material Science and Engineering (85)	18	50
Building and Fire Research (86)	1	100
Computer Systems (87)	0	—
Information Technology (89)	3	67
All	**66**	**58**

TABLE B.34. PROBIT MODEL FOR THE ATP PROJECT BEING MORE TECHNICALLY CHALLENGING THAN THE HYPOTHETICAL PROJECT*

Probit estimates; Number of obs = 65; LR chi2(6) = 11.31; Prob > chi2 = 0.0794;
Pseudo R2 = 0.1272; Log likelihood = –38.7762

Q10d	Coefficient	Standard Error	z	P>|z|
age	–.1449	.0708	–2.05	0.041
lab82	.0722	.6040	0.12	0.905
lab83	–.3276	.7203	–0.45	0.649
lab84	–.9121	.6026	–1.51	0.130
lab85	–.6645	.5706	–1.16	0.244
lab89	–.3765	.8852	–0.43	0.671
constant	1.3902	.5989	2.32	0.020

* The one observation for lab86 is dropped because it is perfectly predicted and there are no observations from lab87 for this question.

TABLE B.35. THE PREDICTED PROBABILITY THAT A PROJECT WILL BE MORE CHALLENGING TECHNICALLY THAN THE HYPOTHETICAL PROJECT

Laboratory	Number of Projects	Probability (rounded %)
Electronics and Electrical Engineering (81)	89	68
Manufacturing Engineering (82)	72	69
Chemical Science and Technology (83)	85	59
Physics (84)	68	36
Material Science and Engineering (85)	115	48
Building and Fire Research (86)	18	100*
Computer Systems (87)	19	—
Information Technology (89)	44	67

* This prediction is based on a single observation and should therefore be discounted accordingly.

From this point, because the sample sizes for the various responses to the hypothetical questions become small, we do not attempt to estimate the maximum likelihood models with control for the sample selection by response to the survey. However, we have been able to do enough estimation with control for sample selection to illustrate how selection into the sample can influence reported statistics. In some cases there is no response effect, but in other cases there is an important effect. We have seen that the control for the correlation in the errors in the response models and the models of substantive interest (regarding the performance of the projects) can at times imply that the average performance of the ATP intramural projects responding to the survey exceeds the performance for the nonresponding projects, although that was not uniformly the case. Certainly the ATP-funded projects have been productive, and the reported observations about the hypothetical questions described in the remainder of this appendix continue to support the conclusion that the ATP-funded projects are very productive.

Table B.36, complementing Table B.25, shows that on average (n = 67), the expected durations of 55 percent of the ATP intramural projects are shorter than for the hypothetical projects.

TABLE B.36. EXPECTED DURATION OF ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Is the expected duration/time to completion longer/the same/shorter?

Laboratory	Number of Projects	Longer (rounded %)	Same (rounded %)	Shorter (rounded %)
Electronics and Electrical Engineering (81)	8	50	0	50
Manufacturing Engineering (82)	14	14	36	50
Chemical Science and Technology (83)	7	14	57	29
Physics (84)	16	0	19	81
Material Science and Engineering (85)	18	17	28	56
Building and Fire Research (86)	1	0	100	0
Computer Systems (87)	0	—	—	—
Information Technology (89)	3	33	33	33
All	**67**	**16**	**28**	**55**

Tables B.37 though B.40 relate to various technical outputs from the ATP intramural project compared to the hypothetical project. Note particularly that many PIs left some or all of these questions blank and thus the number of reporting projects is less than for previous questions. While these small laboratory samples create interpretative problems, the overall percentage responses show that ATP intramural projects, in comparison to the hypothetical projects with similar goals and milestones that would have been undertaken without ATP funding, are expected to lead to more technical papers, more new measurement technology, more or at least the same number of new standards, and the same number of new databases.

TABLE B.37. EXPECTED TECHNICAL PAPERS FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same number of technical papers compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
Electronics and Electrical Engineering (81)	8	100	0	0	0
Manufacturing Engineering (82)	12	75	0	17	8
Chemical Science and Technology (83)	7	71	14	0	14
Physics (84)	17	71	0	18	12
Material Science and Engineering (85)	15	53	13	20	13
Building and Fire Research (86)	1	100	0	0	0
Computer Systems (87)	0	—	—	—	—
Information Technology (89)	2	50	0	0	50
All	**62**	**71**	**5**	**13**	**12**

TABLE B.38. EXPECTED NEW MEASUREMENT TECHNOLOGY FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new measurement technology compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
Electronics and Electrical Engineering (81)	7	100	0	0	0
Manufacturing Engineering (82)	9	56	0	11	33
Chemical Science and Technology (83)	6	17	33	17	33
Physics (84)	15	80	0	0	20
Material Science and Engineering (85)	14	57	7	29	7
Building and Fire Research (86)	1	100	0	0	0
Computer Systems (87)	0	—	—	—	—
Information Technology (89)	1	0	0	0	100
All	**53**	**64**	**6**	**11**	**19**

TABLE B.39. EXPECTED NEW STANDARDS FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new standards compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
Electronics and Electrical Engineering (81)	5	20	0	0	80
Manufacturing Engineering (82)	7	71	0	0	29
Chemical Science and Technology (83)	5	0	20	0	80
Physics (84)	9	67	0	0	33
Material Science and Engineering (85)	4	50	0	0	50
Building and Fire Research (86)	0	—	—	—	—
Computer Systems (87)	0	—	—	—	—
Information Technology (89)	2	50	0	0	50
All	**32**	**47**	**3**	**0**	**50**

TABLE B.40. EXPECTED NEW DATABASES FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE SIMILAR HYPOTHETICAL PROJECT

For those who would have undertaken a project with similar goals and milestones absent ATP intramural funding.

How does this ATP intramural project compare to the project with similar goals and milestones that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new databases compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
Electronics and Electrical Engineering (81)	4	0	0	0	100
Manufacturing Engineering (82)	6	67	0	0	33
Chemical Science and Technology (83)	5	40	20	0	40
Physics (84)	5	0	0	0	100
Material Science and Engineering (85)	4	50	0	0	50
Building and Fire Research (86)	1	100	0	0	0
Computer Systems (87)	0	—	—	—	—
Information Technology (89)	1	0	0	0	100
All	**26**	**35**	**4**	**0**	**62**

Of the 62 responding ATP intramural projects in Table B.37, 71 percent are expected to lead to more technical papers than from the hypothetical projects. Of the 53 responding ATP intramural projects in Table B.38, 64 percent are expected to lead to more new measurement technology. In Table B.39, only 3 percent of the ATP intramural projects are expected to lead to fewer new standards, meaning that 97 percent are expected to lead to more or at least the same number of new standards. And, as shown in Table B.40, only 4 percent of the 26 responding ATP intramural projects expected fewer new databases in comparison to the hypothetical projects, meaning that 96 percent are expected to lead to more or at least the same number of new databases. PIs were similarly asked about patents; the 17 responding projects show that they would be about the same, which is close to zero as noted above.

As shown in Table B.22, PIs responded that for 70 (46 percent) of 151 projects they would have undertaken a project with similar goals and milestones in the absence of funding for their ATP intramural project. For those 81 projects that would not have done so, PIs were asked if they would have alternatively undertaken a project in the same broadly defined research area. As shown in Table B.41, 40 percent of the projects would have been undertaken in the same broadly defined research area. Because the total number of projects that fall within this category is small, only all laboratory means are reported in Table B.42 through Table B.48. Specifically, for those projects that would not have been undertaken with similar goals and milestones but would alternatively have been undertaken in the same broadly defined research area: 52 percent are expected to be broader in scope (see Table B.42); 48 percent are expected to be more technically challenging (see Table B.43); 39 percent are expected to be of shorter duration (see Table B.44); 44 percent are expected to generate more technical papers (see Table B.45); 57 percent are expected to generate more new measurement technology (see Table B.46); 53 percent are expected to generate more standards (see Table B.47); and 69 percent are expected to generate more or at least the same number of new databases (see Table B.48).

TABLE B.41. PROBABILITY OF UNDERTAKING A BROADLY-RELATED RESEARCH PROJECT ABSENT ATP INTRAMURAL FUNDING

If you would not have undertaken a research project with similar goals and milestones in the absence of ATP intramural funding, would you alternatively have undertaken a project in the same broadly defined research area as your ATP intramural project? Yes = 1, No = 0. When making this comparison, please consider a hypothetical project with an amount of funding comparable to your ATP intramural project.

Laboratory	Number of Projects	Probability (rounded %)
Electronics and Electrical Engineering (81)	12	33
Manufacturing Engineering (82)	15	33
Chemical Science and Technology (83)	9	22
Physics (84)	6	100
Material Science and Engineering (85)	23	57
Building and Fire Research (86)	2	50
Computer Systems (87)	3	0
Information Technology (89)	11	9
All	**81**	**40**

TABLE B.42. SCOPE OF ATP INTRAMURAL PROJECT COMPARED TO THE HYPOTHETICAL BROADLY DEFINED PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Is it broader in scope? Yes = 1, No = 0

Laboratory	Number of Projects	Broader in Scope (rounded %)
All	31	52

TABLE B.43. TECHNICAL CHALLENGE OF ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Is it more technically challenging? Yes = 1, No = 0

Laboratory	Number of Projects	More Technically Challenging (rounded %)
All	31	48

TABLE B.44. EXPECTED DURATION OF ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Is the expected duration/time to completion longer/the same/shorter?

Laboratory	Number of Projects	Longer (rounded %)	Same (rounded %)	Shorter (rounded %)
All	31	45	16	39

TABLE B.45. EXPECTED TECHNICAL PAPERS FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same number of technical papers compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
All	27	44	30	19	7

TABLE B.46. EXPECTED NEW MEASUREMENT TECHNOLOGY FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new measurement technology compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
All	21	57	14	19	10

TABLE B.47. EXPECTED NEW STANDARDS FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new standards compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
All	17	53	12	6	29

TABLE B.48. EXPECTED NEW DATABASES FROM THE ATP INTRAMURAL PROJECT COMPARED TO THE BROADLY DEFINED HYPOTHETICAL PROJECT

For those who would not have undertaken a project with similar goals and milestones absent ATP intramural funding but would have undertaken a project in the same broadly defined research area.

How does this ATP intramural project compare to the project in the same broadly defined area that you would have undertaken without ATP funding? Do you think that ATP funding led to more/less/different/same new databases compared to the project that you would have undertaken without ATP funding?

Laboratory	Number of Projects	More (rounded %)	Less (rounded %)	Different (rounded %)	Same (rounded %)
All	16	19	25	6	50

Notes

1. The number of awards is also the number of survey instruments that the PI was asked to complete, and that number is expected to measure the difficulty that the PI faced in responding to the survey.

2. The budget figures were converted to constant 1996 dollars using CEA (2002), Table B7, "Chain-type price indexes for gross domestic product, 1959–2001." The index numbers, 1996 = 100, for gross domestic product were used.

3. The probit model estimates the probability of an event (for example, whether an ATP project PI responds to the survey) for an observation (for example, an ATP Project) as a function of explanatory variables (for example, the budget for the project, or the laboratory where the project occurred). An unobserved indicator variable that takes values from negative infinity to positive infinity is a linear combination of underlying parameters (coefficients) and the explanatory variables plus random standard normal error. When the indicator variable exceeds zero, the event is observed. Thus, the observed response or outcome variable is dichotomous, taking the value one when the event is observed and zero when it is not observed. Given the specification of the unobserved indicator variable, the probability of observing the event given the true parameters and the explanatory variables is the

value of the cumulative normal distribution at the linear combination of the parameters with the explanatory variables. The model therefore allows maximum likelihood estimates of the parameters linking the explanatory variables to the probability of the event being studied. For technical description and details about the probit model (placed in the context of models with discrete outcomes for the dependent variable including count models), see William H. Greene, Chapter 21, "Models for Discrete Choice," *Econometric Analysis*, Fifth Edition (Upper Saddle River, NJ: Prentice Hall, 2003).

4. The maximum likelihood estimates of the parameters are those maximizing the likelihood function (an estimate of the joint probability of the observed outcomes for the sample of observations) for the sample with the given values of the explanatory variables for each observation. For example, the parameters presented include the coefficients on the explanatory variables for the models; the explanatory variables can include the budget for a project, its age, and so forth; the models explain the probability of responding to the survey, the numbers of publications, and so forth; the observations are ATP-funded projects; the samples are collections of those projects.

5. Not all questions were answered on all returned surveys. This applies in particular to Q5. Information collected in Q7 and Q8 is not analyzed quantitatively.

6. The probabilities are predicted from the maximum likelihood probit model with selection—"heckprob" as described in StataCorp (2001) Vol. 2, pp. 31–39.

7. The predictions are made using the "pmargin" option for predictions (StataCorp 2001, Vol. 2, p. 31).

8. *A priori*, one might expect that pre-1997 projects' publication rates would differ from the publication rates for projects in subsequent years. The focus of the intramural awards program changed in 1997 from supporting specific external projects to supporting more broad-based projects. While the 179 reporting projects averaged 5.01 publications each with standard deviation 9.2 and range from 0 to 62, the 82 pre-1997 projects averaged 6.1 publications each with standard deviation 11.6 and a range from 0 to 62, and the 97 reporting projects from 1997 onward averaged 4.1 publications each with standard deviation 6.4 and a range from 0 to 46. However, in the model of publications with control for other variables and for sample selection, the publication rates for the older projects and the more recent ones are essentially the same.

9. The negative binomial model estimates the number of occurrences or events for a "count" variable (for example, the number of publications) for an observation (for example, an ATP intramural project) as a function of explanatory variables (for example, the budget for the project or the laboratory where the project occurred). Given the model's specification of the probability of each of the possible number of occurrences (that is, 0, 1, 2, 3, and so forth) of the event measured by the count variable, the expected value of the count for an observation—given the values of the explanatory variables and the parameters (coefficients) associated with each—is the base for the natural logarithms raised to the power equal to the linear combination of the explanatory variables with their associated parameters. The model allows maximum likelihood estimates of those underlying and

unobserved parameters. The negative binomial model is a generalization of the Poisson model; with the Poisson model, the specification of the probability distribution for the number of events implies that the variance of the number of events equals the expected value of the number of events. The negative binomial model allows for "over-dispersion" in the sense that the conditional variance of the number of events exceeds the conditional mean of the distribution. The conditional mean (the expected number of events given the values of the explanatory variables for the *i*th observation) being denoted as $lambda_i$, then the conditional variance is equal to $lambda_i(1 + (alpha)(lambda_i))$. In the estimated models, the parameter alpha is set equal to 1/theta. The probability distribution is reparameterized in terms of theta rather than alpha to simplify the numerical computations in the maximum likelihood problem. Thus, with the negative binomial results, the values reported for theta show that theta is quite clearly less than one. Alpha is clearly greater than one and there is over-dispersion, appropriately treated with the negative binomial generalization of the Poisson. If alpha equaled zero, the negative binomial model reduces to the Poisson model since then the conditional mean and conditional variance of the probability distribution are equal. Alternatively, the negative binomial model can be interpreted as the result of introducing unobserved individual heterogeneity into the Poisson model. For technical description and details, see William H. Greene, Chapter E20, "Models for Count Data," *LIMDEP, Version 8.0, Econometric Modeling Guide*, Vol. 2 (Plainview, NY: Econometric Software, Inc., 2002). Also, see William H. Greene, Chapter 21, "Models for Discrete Choice," pp. 740–745, *Econometric Analysis*, Fifth Edition (Upper Saddle River, NJ: Prentice Hall, 2003).

10. The latest version of *LIMDEP* has included the program to estimate models for count data with a correction for sample selection. See *LIMDEP Version 8.0 Reference Guide*, "What's New in Version 8.0? WN2.7. Models for Count Data," Greene (2002, p. WN-9): "The Poisson and negative binomial models can be fit with a correction for sample selection. . . . Estimation of the selection model is done by full information maximum likelihood . . . ." We use the full information maximum likelihood model for the negative binomial models with selection estimated in this report.

11. An explanation of the model and the results are available from the authors.

12. See StataCorp. (2001), Vol. 2, pp. 31–39.

13. See StataCorp (2001), Vol. 2, pp. 15–30.

APPENDIX C

Background Information on ATP Projects Not Selected for Case Study

A brief description of the five projects not selected for a detailed case study from the subsample of nine projects considered follows. Detailed descriptions of the four projects selected for case study are included in the body of this report.

PROJECT TITLE: Optimal Design of NIST Microactuators for Precision Machines (and follow on work under the title Deformable Structure Micro Positioners)

Dates of Project and Funding Levels

FY98–FY01
FY98 $240,000
FY99 $270,000
FY00 $180,000

PI/Laboratory

Nicholas Dagalakis
301-975-5845
nicholas.dagalakis@nist.gov
Intelligent Systems Division (823) in MEL (82)

Area of Funding

Electronics and Photonics Technology

Technology

Designed a micro positioner, complete with testing and calibration methods, to be used with flexible automated optoelectronics assembly processes.

Research Achievements with Industrial Relevance

Performance testing and calibration techniques for a new generation of micro positioners with low crosstalk, good lateral resolution, and strong load capabilities for delicate sub-micron automated assembly and positioning applications were developed in response to industry's need for information about how to automate the assembly of optoelectronic products. The micro positioners available at the time the project began were designed for machining or laser interferometry and other types of operations that do not have the same requirements as the work with optical components. Working with consortium members, a planar micro positioner and a six degrees of freedom—x, y, z, yaw, pitch, and roll—micro positioner were developed. By designing the micro positioners and knowing how they worked, NIST could introduce tests and calibrate the micro positioners to study the effects of certain defects, and address the issue of how to calibrate micro positioners for the needs of the optoelectronic types of applications.

Benefits to Industry

- **Actual Benefits to Date**
  Measurement and test methods developed will allow industry to fabricate larger numbers of the devices to provide a low-cost system based on sound calibration, performance measures, and design principles. Also, over time the devices may be able to be reduced in size by using special metals or composites and special fabrication techniques and modified designs.
- **Potential Future Benefits**
  Industrial, research, and applied space laboratories are interested in the micro positioners; however, an effective transfer of the technology into applications will likely require on-site training at NIST of industrial users. NIST has submitted three patent applications. Using CRADAs, interested parties could work at NIST to learn the technology or build the technology in-house and contract with NIST for Dagalakis' time.
- **Industry Contacts**
  Dagalakis has numerous industry contacts.

Recommendation for Inclusion as a Case Study

Recommended as back-up case study

PROJECT TITLE: NIST WebMetrics

Dates of Project and Funding Levels

FY98
FY98 $150,000

PI/Laboratory

Sharon Laskowski
301-975-4535
sharon.laskowski@nist.gov
Information Access Division (894) in ITL (89)

Area of Funding

Information Technology

Technology

Suite of tools and standards applicable to quantifying the usability of a web page.

Research Achievements with Industrial Relevance

WebMetrics (http://www.nist.gov/webmetrics) is a suite of tools and standards. The first tool is called WebSAT, which is a static analyzer tool to evaluate the usability of a web site. The typical usability metrics are efficiency, effectiveness, satisfaction, memorability, and learnability. WebCAT does category analysis ("card sorting" used in the early stages of designing a web site to understand the best way to design the site for its users) on a drag and drop web page. The other tool is WebVIP (variable instrumenter program). It is used to collect the user interaction data for a website. This was the third tool that was initially designed with the ATP funding.

Benefits to Industry

- **Actual Benefits to Date**
  WebMetrics had tools on-line since 1998. There are 100s of hits per month and maybe 50 downloads each month. WebSAT is for use by web designers who are not necessarily usability engineers. WebCAT and WebVIP are used by usability engineers. Industry uses these NIST tools as a starting point, and then customizes the tools with proprietary extensions for their needs.
- **Potential Future Benefits**
  Over the next five to ten years, additional benefits from the WebMetrics tools will be realized. UserWorks is working on a commercial version of WebSAT. Commercial versions of WebCAT may occur. Commercial versions of the visualization tools are underway as well.

Industry Contacts

The president of Userworks is willing to provide information for the project and to provide introductions to other companies that have used WebMetrics. In addition, the "hit" information on the tool at NIST could be used.

Recommendation for Inclusion as a Case Study

Not recommended

PROJECT TITLE: Development of Methodology and Function Security Architecture for Construction of ISO/IEC 15408 Security Protection Profiles for Healthcare Information Systems

Dates of Project and Funding Levels

FY99–FY01
FY99 $200,000
FY00 $150,000
FY01 $200,000

PI/Laboratory

L. Arnold Johnson
301-975-3247
l.johnson@nist.gov
Computer Security Division (893) in ITL (89)

Area of Funding

Information Technology

Technology

Secure IT for healthcare information systems is a goal of both standards organizations and public policy. BACKGROUND: The key public policy framework for the work is the Health Insurance Portability and Accountability Act (HIPAA). (The Act is also called the Kassebaum Kennedy Bill and was passed on August 21, 1996.) Among other things, the Act calls for development and enactment of standards that would reduce costs in the administration of healthcare by enabling standardized, electronic transmissions of transactions that have been recorded on paper. Simplification and standardization of administrative information would be required for such an electronic IT system for healthcare. Further, because such a system would increase the risk of inappropriate access to sensitive information, HIPAA calls for the development and enactment of security standards and privacy legislation. Congress mandated that the Health Care Financing Administration (HCFA) in the Department of Health and Human Services would be responsible for implementing the standardization of administrative information and security standards for healthcare. HCFA issued a notice of the proposed rule making in the Federal Register as "Security and Electronic Signature Standards; Proposed Rule," Federal Register, Vol. 63, No. 155, August 12, 1998, pp. 43269-43271. The HCFA proposed rule, called the "proposed HIPAA security requirements," will apply to claims clearing houses, health plans, employers, and healthcare providers. The key standards organization basis for the work is ISO/IEC 15408, from the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). The ISO/IEC International Standard 15408 provides the description of the process support facilities that are needed to develop functional requirements for security and evaluation benchmarks for IT security systems that will conform to the HCFA Internet security policy requirements. Three process support facilities are defined by ISO/IEC 15408. (1) Persons procuring healthcare IT systems have a standardized way to articulate security requirements. (2) Vendors of the healthcare IT systems have a way to claim compliance with the requirements by describing the security features of their products. (3) IT security evaluators have benchmarks for evaluating the products to ensure compliance with HCFA Internet security policy.

Research Achievements with Industrial Relevance

(1) An ISO/IEC 15408 functional package for systems transmitting HCFA data was developed. It is a collection of functional requirements for the security of healthcare IT systems that conform to the requirements in the HCFA Internet security policy.
(2) An ISO/IEC 15408 protection profile (PP) for admissions discharge and transfer (ADT) systems in healthcare organizations was developed. It is a framework for stating the functional requirements and the assurance requirements for security for an IT product or system.
(3) A methodology for the development of security architectures for healthcare systems was developed.
(4) Access control frameworks for healthcare information systems were proposed. Decision rules use temporal business association constraints and, following HIPAA, include features to ensure the security of multiple types of authorizations—user-based, role-based, and context-based authorizations as well as capabilities for making emergency authorizations.
(5) Several subsequent efforts include: (a) Two projects funded by the National Information Assurance Partnership (NIAP), a joint program of NIST and the National Security Agency (NSA), under NIAP Contract MDA904-00-P-4292. "HIPAA Security Policy Package for Healthcare Security Systems with Internet Capability," Arca Systems, Inc., January 25, 2001, and "HIPAA Policy Package Guidance and Rationale," Arca Systems, Inc., January 25, 2001. (b) R&D work for additional HIPAA protection profiles.

Benefits to Industry

- **Actual Benefits to Date**
  The functional package can be used as a prototype for applications with traceability through NIST to HIPAA requirements. It is a reusable module that can be used to document the security requirements for a user's information system. The requirements map to the common criteria in ISO 15408, and NIAP validates testing laboratories' test results for vendors' products designed to meet the specifications of users' protection profiles. The testing laboratories are accredited by the National Voluntary Laboratory Accreditation Program at NIST.
- **Potential Future Benefits**
  The functional package will be a prototype for industrial applications and will evolve into the actual NIST traceable healthcare security infrastructure technology of the future. Further, the NIST work in this intramural project has applications beyond healthcare, so there will be additional spillover effects for security of information technology in other industries as well.

Industry Contacts

CEO of HIPAAdocs, a company specializing in HIPAA compliance, can assist in the study and can identify others who are about to benefit from this technology.

Recommendation for Inclusion as a Case Study

Not recommended

PROJECT TITLE: Fundamental Studies of Dislocation Structures During Deformation

Dates of Project and Funding Levels

FY98–FY00
FY98 $170,000
FY99 $100,000
FY00 $75,000

PI/Laboratory

Richard Fields
301-975-5712
richard.fields@nist.gov
Metallurgy Division (855) in MSEL (85)

Area of Funding

Information Technology

Technology

3-D computer code to predict stress, strain, fracture, and geometrical imperfections for the forming of metal.

Research Achievements with Industrial Relevance

The metal forming research program began at NIST in the early 1990s. In 1995, ATP funded two projects under the Motor Vehicle Manufacturing Technology Focus Program, and Fields' research program grew through his association with these projects. This project led to the formulation of a set of equations to use in software, and that software will be sold to companies in the metal forming industry. The software will predict how the metal will deform given the stress it receives during particular forming processes.

Benefits to Industry

- **Actual Benefits to Date**
  NIST interacts with industry on a regular face-to-face basis and through publications. Through these interactions, industry is learning more, and at a faster rate, about cost-effective predictive solutions to forming metal to conform to engineering designs.
- **Potential Future Benefits**
  The ATP project gave the metal forming research program at NIST industrial visibility and relevance. Subsequently three projects have been undertaken, which would not otherwise have occurred: (1) fundamental dislocation science, (2) surface roughening, and (3) multi-axial deformation standards.

Industry Contacts

Fields has identified several industrial contacts who can speak to the importance of the research at NIST.

Recommendation for Inclusion as a Case Study

Not recommended

PROJECT TITLE: Machine Tool Characterization Monitoring and Control

Dates of Project and Funding Levels

FY96–FY98
FY96 $260,000
FY97 $280,000
FY98 $230,000

PI/Laboratory

Alkan Donmez
301-975-6618
alkan.donmez@nist.gov
Automated Production Technology Division (822) in MEL (82)

Area of Funding

Information Technology

Technology

Characterization, monitoring, and control of spindles in machine tools.

Research Achievements with Industrial Relevance

Geometric errors are inherent in any mechanical elements of machining. Accurate cutting requires knowledge of the geometric errors and how to compensate for them, and the intramural research developed such knowledge. Most machine tools have spindles; spindles either turn the work or turn the tool. The characteristics of spindles are important for cutting accuracy. The project produced new knowledge about the axis of rotation for spindles, how to measure their characteristics, and how to relay the information to other parties. Specifically, it (1) led to a reevaluation of several existing standards to characterize spindles, and (2) established a research relationship with the University of Michigan and with a company in Michigan to transfer some of this technology into practice in commercial use.

Benefits to Industry

- **Actual Benefits to Date**
  Performance and measurement standards for machine tools are important to users to avoid unnecessary scrap and rework. Use of the research underlying these standards has reduced operating costs in a number of companies (for example, at Caterpillar and at Boeing)
- **Potential Future Benefits**
  Once the new standards are implemented, spindle buyers will have greater knowledge of the machine tools they purchase. As a result, scrap and rework will decline, and thereby costs will fall in the many industries where the new standard is applied.

Industry Contacts

Timken Research reports the company has been able to introduce several new products as a result of the ATP-sponsored NIST research to develop new standards for spindles. Further, the company has been able to gain customer confidence because of traceability to NIST. Other small companies that have benefited in the same ways can be identified.

Recommendation for Inclusion as a Case Study

Not recommended

APPENDIX D

Publications, Conference Presentations, and Research Accomplishments from the Case Study Projects

Wavelength Reference for Optical Fiber Communications: SRM 2517a

Eight articles have been published from this project to date.[1]

Gilbert, Sarah L., and William C. Swann. "Wavelength calibration standards for wavelength division multiplexing," in *Proc., 1999 Optical Fibre Meas. Conf.*, Nantes, France, Sept. 22–24, 1999.

———. "Accurate wavelength calibration for wavelength division multiplexing," in *Optical Fiber Communication Conference*, OSA Technical Digest (Optical Society of America, Washington, DC, 1999), pp. 267–269.

———. *Acetylene Absorption Reference for 1510 nm to 1540 nm Wavelength Calibration—SRM 2517a*, NIST Special Publication 260–133, 2001 Edition, *Standard Reference Materials*, Issued February 2001 (Washington, D.C., U.S. Government Printing Office, 2001).

Gilbert, S.L., W.C. Swann, and T. Dennis. "Wavelength standards for optical communications, *Proceedings of the Laser Frequency Stabilization, Standards, Measurement, and Applications Conference* (SPIE Conference 4269), January 25–26, 2001, San Jose, California, pp. 184-191.

Swann, W.C., and S.L. Gilbert. "Pressure-induced shift and broadening of 1510–1540 nm acetylene wavelength calibration lines," *J. of Opt. Soc. Am. B*, vol. 17, no. 7, July 2000, pp. 1263–1270.

Gilbert, S.L., T. Dennis, and W.C. Swann. "Wavelength References for Wavelength Division Multiplexing," in *Proc., Workshop on Contemporary Photonic Technologies*, Tokyo, Japan, January 15–17, 2001, pp. 143–146.

Gilbert, S.L., S.D. Dyer, P.A. Williams, and A.H. Rose. "Optical Metrology for Wavelength Division Multiplexed Fiber Communications," *Optics and Photonics News*, Vol. 12 No. 3, March 2001.

Gilbert, S.L., and W.C. Swann. "Wavelength Control and Calibration for Wavelength Division Multiplexed Optical Communication," in *Proc., 2001 IEEE/EIA International Frequency Control Symposium*, (IEEE, Piscataway, NJ, 2001) pp. 122–126.

Presentations of the project's output have also helped to transfer the technology to industry. The project resulted in approximately 15 professional presentations outside of NIST, including:

Conferences: Optical Fiber Communication Conference (contributed talk in 1999, invited talk in 2002), Optical Fibre Measurement Conference (invited talk, France), Workshop on Contemporary Photonic Technologies (invited talk, Japan), SPIE Laser Frequency Stabilization, Standards, Measurement, and Applications Conference (invited talk), IEEE/EIA International Frequency Control Symposium (invited talk), Optical Society Annual meeting (invited talk), American Scientific Glassblowers Society Annual Symposium (Keynote talk), Council for Optical Radiation Measurements Conference (invited talk), Australasian Conference on Optics, Lasers, and Spectroscopy.

Seminars at Universities & Companies: University of Oxford Physics Department, University of Colorado, Photonics Research Laboratory (University of Melbourne), University of Southampton Optoelectronics Research Centre, Corning, Inc.

Composite Bone Grafts

Four articles have been published from this project to date: [2]

C.A. Khatri, J.F. Hsii, and F.W. Wang. "Moldable Composite Bone Grafts Consisting of Calcium Phosphate Cement and Biodegradable Polymer Microspheres: Mechanical Properties and Controlled Release of Bioactive Molecules," *Transactions of the 28th Annual Meeting of the Society for Biomaterials*, 728, April 2002, Tampa. FL.

Carl G. Simon Jr., Chetan A. Khatri, Scott A. Wight, and Francis W. Wang. "Preliminary Report on the Biocompatibility of a Moldable, Resorbable, Composite Bone Graft Consisting of Calcium Phosphate Cement and Poly (lactide-co-glycolide) Microspheres," *Journal of Orthopaedic Research*, 2001; 20:473.

C.G. Simon Jr., and F.W. Wang. "Seeding Cells into Calcium Phosphate Cement," *Transactions of the 28th Meeting of the Society for Biomaterials*, 222, April 2002, Tampa.

F.W. Wang, C.A. Khatri, J.F. Hsii, S. Hirayama, and S. Takagi. *IADR Abstract*—"Polymer-Filled Calcium Phosphate Cement: Mechanical Properties and Protein Release," *Journal of Dental Research*, 2001; 80:591.

One article is in press:

F.W. Wang, C.A. Khatri, J.F. Hsii, S. Hirayama, and S. Takagi. "Polymer-Filled Calcium Phosphate Cement: Mechanical Properties and Controlled Release of Growth Factor," *Biomedical Engineering: Recent Developments*, edited by J. Vossoughi.

Two additional articles are under review, one at *Applied Biomaterials* and the other at *Journal of Biomedical Materials Research*. And, six professional presentations have already been given outside of NIST.

In addition to publications, Dr. Wang's intramural project led to the development of a new measurement method to characterize quantitatively the biocompatibility, the degradation behavior, and the drug release of composites that are made of a ceramic material and a particulate polymer.

Also, the results from this intramural project facilitated additional funding from NIDCR for a project entitled, "Innovative Composite Bone Grafts through Measurement Science."

The knowledge gained through Dr. Wang's research in this intramural project facilitated the successful completion of a study funded through ATP's tissue engineering focused program. In October 1997, $2 million was awarded to Integra LifeScience Corporation to conduct a study called, "Biocompatible Resorbable Polymers Designed for Tissue Engineering." According to the ATP Project Brief, the purpose of this study by Integra was to: "Synthesize and characterize biocompatible polymeric implant materials with the structural, chemical, and biological properties needed to support cartilage repair, potentially a billion dollar market in the U.S."

Internet Commerce for Manufacturing

Six articles have been published from this project:

Barkmeyer, Edward, James Nell, and Curtis Parks. "Internet Commerce for Manufacturing Activity Models," NISTIR 6516, May 3, 2000.

Goldstein, Barbara (ed.). *Proceedings of the National Institute of Standards and Technology (NIST) Internet Commerce for Manufacturing (ICM) Scenario Development Workshop*, Chicago: IPC Headquarters, January 1998.

Goldstein, B., and T. Rhodes. "Integrating Manufacturing Across Electronics Supply Chain Partners: the NIST Internet Commerce for Manufacturing Project," *Engineering Development International*, September 2000.

Ivezic, N., E. Fong, Y. Peng and T. Rhodes. "B2B e-commerce Infrastructure using Agents and Standards—A Potential Impact Analysis and Architecture," *Proceedings of the 4th International Conference on Design of Information Infrastructure Systems for Manufacturing (DIISM)*, November 2000.

Nell, James, and Curtis Parks. "Internet Commerce for Manufacturing Data Staging," NISTIR 6578, November 8, 2000.

Parks, Curtis. "Internet Commerce for Manufacturing Product Data, NISTIR 6320, April 14, 1999.

And, eight professional presentations have been given outside of NIST to date.

Polymer Composite Dielectrics for Integrated Thin-Film Capacitors

Dr. Obrzut's intramural ATP-funded research has laid the foundation for a new IPC standard dielectric test method in the range of 100 MHz to 10 GHz. Work on the new IPC test method standard for embedded passives (IPC-4902 Task Group 3-13) is currently under development.

The ATP project has also generated several published papers, a report, a workshop, five presentations, an invention disclosure, a testing methodology, and a confidential agreement between NIST and the National Center for Manufacturing Science.

Publications have documented the output from the project and helped to transfer the technology to industry.

Noda, N., and J. Obrzut. "High frequency dielectric relaxation in polymers filled with ferroelectric ceramics" manuscript accepted for *MRS* publication.

Obrzut, J., in "Embedded Decoupling Capacitance Project Final Report," *NCMS Report 0091RE00*, December 2000, NCMS 3025 Boardwalk, Ann Arbor, Michigan 48108.

Obrzut, J., and D. McGregor. "Test Method for Embedded Passive Devices 100 MHz–5 GHz, (high-k / low impedance films)," IPC Embedded Passive Devices Task Group, 3–12j, October 16, 2001, Orlando FL.

Obrzut, J., and R. Nozaki. *IEEE IMTC*/2001, vol. 2. pp. 1000–4.

Obrzut, J., N. Noda and R. Nozaki. "Broadband Dielectric Metrology for Polymer Composite Films", *IEEE Annual Report 2001 on Insulation and Dielectric Phenomena*, pp. 269–72, 2001.

———. "Broadband Characterization of Dielectric Films for Power-Ground Decoupling," accepted for *IEEE Transaction on Measurements Instrumentation Special Issue* (2002).

Popielarz, R., C.K. Chiang, R. Nozaki, and Jan Obrzut. *Mat. Res. Soc. Symp. Proc.* Vol. 628, pp. CC 11.5.1–6, 2000

Presentations of the project's output have also helped to transfer the technology to industry. The groups to which the presentations were made include industry groups developing new packaging technologies (NCMS), standard test committees (IPC), and academic research groups (MRS and APS)

In addition to the publications and presentations, the project produced an invention disclosure:

J. Obrzut and R. Nozaki, Test Fixture for Permittivity Measurements of Dielectric Films at Microwave Frequencies," NIST Docket # 01-019PA, 2001, the testing methodology for high-k film substrates.

As well, a confidential agreement was signed between NIST and the National Center for Manufacturing Science (NCMS) where applications of embedded passives is under development.

NOTES

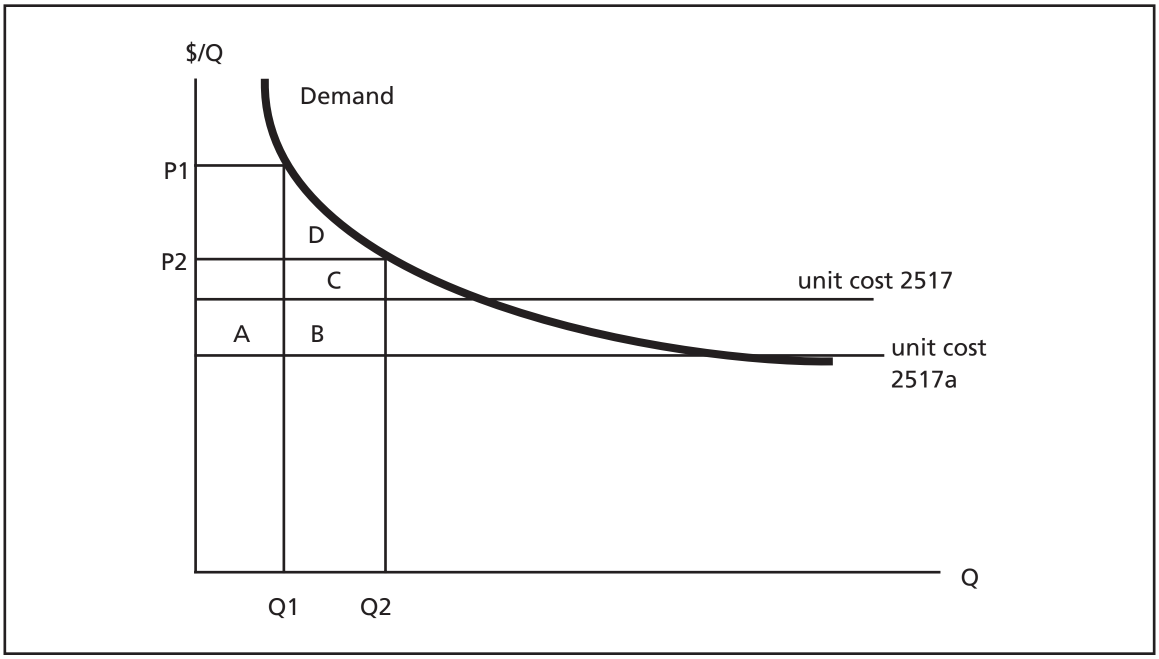
1. This information comes from Dr. Gilbert's responses to the electronic survey.
2. This information comes from Dr. Wang's responses to the electronic survey.

APPENDIX E

Alternative Approach to the Calculation of Evaluation Metrics for the SRM 2517a Case Study

The metrics in Table 9 in the report reflect the social return on investments, and these are the returns that economists call producer surplus. Producer surplus is the profit resulting because of the use of the infratechnology embodied in SRM 2517a.[1] Although the estimate will be a rough one, we are able to provide a first-order approximation of the consumer surplus gains as well. To understand those gains, refer to Figure E.1. It represents the situation for the typical company selling a differentiated product that uses SRM 2517a in the production process. The availability of the new standard reference material lowers the unit costs as shown in the figure from "unit cost 2517" to "unit cost 2517a." Consequently, the company chooses a lower price and sells more of its product or service.[2] The company's profit maximizing price falls from P1 to P2, and the optimal output increases from Q1 to Q2. The new surplus—resulting because of the new lower unit costs of production enabled by SRM 2517a—is the sum of the areas A, B, C, and D. Area A represents the new producer surplus on sales of the original amount of output. Area B plus area C represents the new producer surplus from the sale of additional output. Finally, area D represents the net gain in consumer surplus (new consumer surplus that does not simply offset a loss in previously existing producer surplus).

FIGURE E.1. DEMAND, UNIT COST, AND NET GAIN IN PRODUCER AND CONSUMER SURPLUS FROM THE USE OF SRM 2517A



Appendices

Details about price, output, and unit cost are considered highly confidential and the industry respondents were typically unwilling to provide such information. However, one of the respondents was willing to provide detailed information, for its own production, about P1, P2, Q1, Q2, and unit cost both before SRM 2517a was introduced and then after it replaced SRM 2517. For that company, the ratio of net new consumer surplus to new producer surplus, D/(A + B + C), equals 0.238. That company conjectures that its experience with the cost-lowering effect of replacing SRM 2517 with SRM 2517a would be similar to the experiences of others in the industry. Therefore, as a first-order approximation of consumer surplus gains because of the process innovations from applying SRM 2517a, we multiply the new producer profits—the industry benefits column of Table 8 in the report by 0.238. Table E.1 recalculates the metrics for the SRM 2517a project by using the total of the net gains in producer and consumer surplus (the industrial benefits from Table 8 in the report multiplied by 1.238) as the social return on the investment.

TABLE E.1. REVISED EVALUATION METRICS FOR THE SRM 2517A CASE STUDY USING TOTAL BENEFITS (NET GAINS IN THE TOTAL OF PRODUCER SURPLUS AND CONSUMER SURPLUS) (YEAR 2000 DOLLARS)

Metric	Estimate
Real Internal Rate of Return	5,500%
Benefit-to-Cost Ratio	331 to 1
Net Present Value using 1998 as the base year in year 2000 dollars	$72.0 million
Net Present Value using 2002 as the base year in year 2000 dollars	$94.4 million

NOTES

1. As is seen in Figure E.1, in addition to gaining new profits that we have identified as industrial benefits, industry loses some of its previous profits on the previous amount sold before unit costs fell because the use of SRM 2517a lowers costs and consequently price falls. However, those lost profits (lost producer surplus) are completely offset by a gain of exactly that amount in consumer surplus, leaving just the new profits measured in Table 8 in the body of the report, and represented by A + B + C in Figure E.1 as the increase in total surplus because of increased producer surplus. The net gain in consumer surplus (represented by D in Figure E.1) is then added to get the change in total economic surplus that is the social return to the use of SRM 2517a—consumers gain more than D, but that additional gain is exactly offset by an equal amount of lost previously existing surplus for producers, leaving D as the net gain in consumer surplus.

2. Note that Figure E.1 depicts optimal output in the long run when all costs are variable.

About the Advanced Technology Program

The Advanced Technology Program (ATP) is a partnership between government and private industry to conduct high-risk research to develop enabling technologies that promise significant commercial payoffs and widespread benefits for the economy. ATP provides a mechanism for industry to extend its technological reach and push the envelope beyond what it otherwise would attempt.

Promising future technologies are the domain of ATP:

- Enabling technologies that are essential to the development of future new and substantially improved products, processes, and services across diverse application areas.
- Technologies for which there are challenging technical issues standing in the way of success.
- Technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations.
- Technologies which will go undeveloped and/or proceed too slowly to be competitive in global markets without ATP.

ATP funds technical research, but it does not fund product development. That is the domain of the company partners. ATP is industry driven, and that keeps it grounded in real-world needs. For-profit companies conceive, propose, co-fund, and execute all of the projects cost shared by ATP.

Smaller companies working on single-firm projects pay a minimum of all the indirect costs associated with the project. Large "Fortune 500" companies participating as a single firm pay at least 60 percent of total project costs. Joint ventures pay at least half of total project costs. Single-firm projects can last up to three years; joint ventures can last as long as five years. Companies of all sizes participate in ATP-funded projects. To date, two out of three ATP awards have gone to individual small businesses or to joint ventures led by a small business.

Each project has specific goals, funding allocations, and completion dates established at the outset. Projects are monitored and can be terminated for cause before completion. All projects are selected in rigorous competitions that are peer reviewed to identify those that score highest against technical and economic criteria. Contact the ATP for more information:

- On the World Wide Web: http://www.atp.nist.gov.
- By e-mail: atp@nist.gov.
- By phone: 1-800-ATP-FUND (1-800-287-3863).
- By writing: Advanced Technology Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 4701, Gaithersburg, MD 20899-4701.

About the Authors

Albert N. Link is professor of economics at the University of North Carolina at Greensboro. He received a B.S. degree in mathematics from the University of Richmond in 1971 and the Ph.D. in economics from Tulane University in 1976. His research interests are broadly within the area of technology and innovation policy, and his current projects relate to public policy evaluation methods and university research strategies. He is editor of the *Journal of Technology Transfer* and has served on National Academy of Sciences and National Science Foundation advisory committees. In addition, he has consulted on science and technology policy for numerous governments as well as for the European Commission, the World Bank, and the Organization for Economic Co-operation and Development.

John T. Scott received the Ph.D. in Economics from Harvard University and the A.B. in Economics and English from the University of North Carolina at Chapel Hill. He holds the position of Professor of Economics at Dartmouth College. His teaching and research are in the areas of industrial organization and the economics of technological change. He has served as the President of the Industrial Organization Society and on the editorial boards of the *International Journal of Industrial Organization*, the *Review of Industrial Organization*, and *The Journal of Industrial Economics*. He has consulted in matters of technology policy for the National Institute of Standards and Technology, the National Science Foundation, the National Academy of Sciences, the World Bank, and the Organization for Economic Co-operation and Development. He has served as an economist at the Board of Governors of the Federal Reserve System and at the Federal Trade Commission.