Research Project Impact Analysis

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ABSTRACT: Sandia National Laboratories (SNL) funded a study at the University of New Mexico to revisit two examples of technology transfer from SNL for the purpose of measuring their full social return and to develop a standard method for making such evaluations. This article describes the comprehensive and systematic template composed of seven steps developed to measure the impact of R&D and reports the findings of the study, providing insight into the social value of research. The cost benefit ratio for society, when counting the cost of developing one technology at SNL for defense related purposes, was 1:4 and, using the most conservative estimates, for the second technology, the ratio was 1:30.

KEY WORDS: Research and development (R&D), and value impact analysis

Public sector scientists and engineers have a natural reluctance to place "value" on their work in research and development (R&D). They view R&D as an essentially intellectual and clearly beneficial pursuit.

Public sector scientists and engineers are, however, under increasing pressure to identify and measure the impacts of their research to justify further funding. This demand arises from a combination of budgetary pressures, the realignment of political power, and increasing competition from the growing number of researchers.

Indeed, the conventional view that such measurement is too complex, speculative, and time intensive to be practical is no longer tenable. The relevant question is rapidly becoming how, rather than whether, to develop measures to validate continued public support of specific R&D activities.

What will cause the public to support R&D? In the past, doing good science was considered sufficient. Good science has meant demonstrating that the scientific method was correctly employed to expand the basic, applied, or developmental knowledge frontier as identified by each scientific discipline's experts.

Belief in the linear model of innovation—science progress leads sequentially to economic progress—undergirded this sufficiency, in theory. While politicians and policy makers may not be fully cognizant of the theoretical underpinnings of their decisions (i.e., innovation is now known to be better represented by nonlinear models [6,10]), they are aware that the link between research and the achievement of societal goals through fulfillment of public organizational missions (at costs society is willing to pay) needs to be made more explicit to withstand the increasing scrutiny of competitors for public funds. The assumption here is that this new thrust of R&D measurement will make the link sufficiently clear to garner the support necessary to both sustain public sector R&D and improve the quality and efficiency of publicly funded research, ensuring it is worthy of that support.

The purpose of this article is to provide specific guidelines for public sector R&D impact evaluation and metrics. A seven step process leading to a comprehensive evaluation of the impact of research and development is used as an organizing framework. We take as our point of departure the fact that publicly funded research, while subject to net benefit criteria, must also contribute to the wider set of goals that distinguish the public sector from the private sector. Thus, while economic criteria must be included, they must be included in a way responsive to public goals and as one of several relevant criteria. We therefore include a variety of indicators to generate the fullest possible description of the project, realizing all cannot be precisely measured for every project. The aim is to provide a common framework for comparing projects, built up from the sub-project level.

Public Sector R&D Evaluation

What is sought in public sector R&D is success achieved by attention to goals, wisely planning spending through the use of near-term metrics, and the generation of historical metrics to validate or refute past spending decisions relative to guiding, not binding, criteria. There is, however, very little agreement about how to specify these criteria. Public R&D impact has been gauged by bibliometrics (citation and co-citation analysis); peer review; participation counts for training/education activities and for mechanisms designed to facilitate technology transfer; science user or customer surveys; and publication, patent, copyright, and product counts [2]. Although each of these metrics adds information, the meaning of the information is not clear because of the inherent limitations of this surrogate data.

For example, reviewers are subject to the bounds of human rationality, cognitive capacity, and bias. Therefore, peer review can potentially yield arbitrary, biased, or other than rational outcomes [3]. Publication or patent counts measure a representation of R&D output, rather than the output itself. The number of citations, while communicating the existence of linkages, may not be instructive concerning the importance, quality, or relative impact of the work within a field or subfield because of differences between disciplines in citation, peer communication, and information flow patterns [8].

In addition, demarcation of the boundaries necessary for quantification may be somewhat arbitrary. For example, the lifetime of a technology can be measured from either invention or market introduction to the replacement by its sequel or to complete obsolescence of the technology. A second difficulty is whether (and if so, how) to apportion responsibility for commercialization between R&D and entrepreneurship. Complexity of measurement may increase when research output diffuses across several industries, requiring data to be gathered from many geographically dispersed organizations and locations.

Despite these limitations, data is still needed to answer the policy maker's question: What impact on industrial products, processes, services, and productivity will public sector R&D investment yield? Though many R&D outputs are not monetizable (i.e., What is the dollar value of one conference presentation?), to be included here they must be quantifiable. As noted, once impacts are enumerated, R&D managers will ultimately require a method to compare the R&D outputs of competing projects. To satisfy the need for comparable data, we argue for standardization of comprehensive measurement. All available data, both monetized and non-monetized, should be reported to the evaluation audience in a standardized format.

Comprehensive, as used here, is intended to mean complete, extensive, thorough and, most importantly, inclusive. In the private sector, one value has preeminence—net revenue, that is, contribution to profits. In the public sector, market values compete with values that derive from the responsibility of governance. Thus, the public sector considers values such as equity (or distributional issues), due process (or fairness issues), effectiveness, representativeness and participativeness (democratic process) as well as contributions to the quality of the environment and quality of life. As a result, impact assessment in the public sector will necessarily include metrics that would be considered improper from a pure economic perspective.

The fact that we are using multiple criteria means that the basic unit of observation takes on greater importance. For example, R&D impacts can be observed at the following eight levels:

1. individual consumer(s);
2. individual firm;
3. subset of specialized firms within an industry;
4. all firms within an industry;
5. multiple industries within an economy;
6. all industries within an economy;
7. multinational economies; and
8. worldwide.

From an economic perspective, the only impacts that are appropriate to include in the assessment of domestic public sector investment are those that cause measurable change at level six, the aggregate economy. From an equity perspective, if the subset of firms in level three is firms within a particular geographic region, targeted by government, for special treatment (like inner city neighborhoods or economically depressed regions), the impact of public sector investment in that region may be an additional appropriate impact to assess (See Appendix A).

Likewise, concerns over other criteria might focus on individuals, demographic subsets, tribal nations, or even the world—for topics like global climate change. Perhaps most important, in creating evaluation metrics, care must be taken to avoid double-counting when moving from perspective to perspective. With that realization in mind, a list of possible R&D impacts is shown in Table 1. The list is reflective of current literature and may well be extended by future work.

The impacts are categorized into the following four areas: economy, technology/knowledge, environment, and health. (The first two areas represent a classification of metrics commonly reported in articles and reports on R&D and technology transfer evaluation. To these were added the areas of environmental and health/quality of life impact).

The two sections of impacts in the area of economy are distinguished as monetized or non-monetized. Monetized metrics are separated into costs and benefits. Monetized costs were categorized as either capital, equipment, or labor. Benefits are measured with estimates of net profits, cost savings, and revenue generated from patents or license agreements. The monetized metrics are used to conduct cost/benefit analysis.

Non-monetized metrics are separated into positive impacts and negative impacts. Positive R&D impacts are measured using the following counts: new business start-ups, successive types of users, jobs; and percent of industry dispersal.

Successive types of users refers to the number of types of industries that use or receive benefit from the research output. Industry dispersal refers to the number of firms (reported as a percentage) within the technology's base industry that have implemented the technology.

In regard to job counts, to present an accurate accounting of impact, it may seem reasonable to reduce the credit for the prosperity engendered by the successful commercialization of a new technology by an accounting of the loss of sales and workers displaced by the replacement of the existing technology. However, technology is necessarily destructive and creative simultaneously. As the old technology is made obsolete, the new technology increases the efficiency of resource usage. The resources that are unused by the more efficient new technology and would have been expended using the old, are now free to be applied to a more efficient use. In a moderately competitive economy, the displaced workers are only temporarily, not permanently, unemployed. Society experiences a net gain, not loss, from new technology. Therefore, since it would, in the long term, misrepresent the true impact to reduce impact by the effects of the replacement of the old technology, that reduction is not commonly included in assessments of the impact of new technology and is not recommended here. Job counts should be reported as gross not net new jobs.

In the area of Technology/Knowledge, the impact of R&D is measured by counts of tangible outputs of the R&D (products, devices, incremental improvements, the solving of significant universal problems, and algorithms /software) and surrogate measures of these outputs (patents, publications/presentations, postdoctoral research, and industry training). Significant, universal problems extend beyond the scope of the R&D project being assessed, creating hindrance or difficulty in other scientific or technical endeavors and are therefore worthy of measurement. It is important to note that while the aggregate of the enumerations for the four areas of impact will create an overall profile of impact, the assertion is not being made here that the individual enumerations (for example the number of patents) equate to impact because the enumerations alone may only represent potential rather than actual impact.

The impact in the area of environment is measured by estimates of known increments or decrements to the number of pollutants in the air, water, or waste related to the R&D. The pollutants are qualitatively graded to indicate the severity of the risk they pose and reported according to the number of pollutants within each grade. (The grading and evaluation, to be consistent with current legal reporting requirements, should be done in accordance with the rules that the EPA, state, or local environment agencies have developed to implement legislation such as National Environmental Protection Act (NEPA), 1970; Toxic Substances Control Act, 1970; and National Clean Water Act (1977,1981,1987); National Clean Air Act, etc.)

In regard to health/quality of life, data on changes in accident or death rates related to the R&D are reported for the employees within industries and for the public, if applicable and significant. Estimates of verified influence on changes in longevity or quality of life for employees and for the public, if applicable and significant, will also be sought.

The differences in R&D projects and constraints on resources and data availability preclude obtaining data for each metric at each level for every R&D project, since R&D impact can range from worldwide to exclusively local. However, the recommendation here is to obtain data for as many indicators as availability and appropriateness permit. We now turn to the recommended seven steps to standardize comprehensive public R&D impact evaluation.

Seven Public R&D Evaluation Steps

<u>**Step 1**</u>: Sketch an innovation time line from the inception of this research area or technology to the present day.

The purpose of this step is threefold. First, an innovation time line marks the major milestones that have occurred in this area of research. This, by necessity, also identifies the important problems or needed advances or improvements that have existed and those that continue to exist (the appropriate prioritization of the current needs in the research area or technology should become apparent), resulting in a "state of the technology/research area" profile. Second, this familiarity with the research area or technology's history helps to differentiate major advances from incremental improvements and their associated impacts. Third, participation of or feedback from the technical or scientific community of customers is a necessity to adequately complete this step. The participation of this community will increase the likelihood that the research will be timely and have optimal impact.

It warrants mention that this method is intended to improve and assist the conduct and measurement of public sector R&D rather than complicate or impede it. The level of effort to complete this step, for example, should be on the order of the following. The scientist or engineer should seek to verify their own knowledge of the research area's innovations by consulting experts in the area, review articles, proceedings presentations, or texts published within the last three years. The key features of the resources consulted are that they should be credible and as current as possible.

Step 2: Identify all potential or actual clients/ customers/ beneficiaries of the research /technology project.

The purpose of this step is to broaden the researcher's perceived set of "clients or customers" of the research. It is important to identify the users, clients, customers and beneficiaries that will make use directly or indirectly of the research results. Identify here means specific individuals in specific organizations (at minimum two or three individuals representative of the majority) rather than types of organizations or names of industries.

ECONOMY	
COSTS	BENEFITS
(cost of producing knowledge) *capital purchase new buildings *equipment purchase equipment/materials > $10,000 *labor wages (including overhead) subcontracts training/reskilling costs (cost of transfer) *capital *equipment *labor	*net profits *cost savings product, process, service cost savings cost savings from more efficient building use cost savings from reducing equipment needs cost savings from more efficient labor use *revenue from licenses
NEGATIVE IMPACTS	POSITIVE IMPACTS
	create/save jobs start-up new business industry dispersal successive types users increase US market share retain domestic industry improve balance of trade
ECONOMY TECHNOLOGY/INFORMATION	
NEGATIVE IMPACTS	POSITIVE IMPACTS
	new products incremental product improvements new processes new devices new algorithms/software new copyrights new patents citations new patents successfully solved problems new tests, codes, standards, calibrations new publications citations new publications new technical reports post doctoral research projects collaborative industry projects collaborative university projects follow-on research projects
ENVIRONMENT	
NEGATIVE IMPACTS	POSITIVE IMPACTS
new air pollutants new water pollutants new soil contaminants new waste production	abate air pollutants abate water pollutants abate soil contaminants abate waste production
HEALTH/QUALITY OF LIFE	
NEGATIVE IMPACTS	POSITIVE IMPACTS
increase incidence of disease increase accidents increase worker mortality decrease longevity decrease safety decrease personal freedom	decrease incidence of disease decrease accidents decrease worker mortality increase longevity increase safety increase personal freedom percent of society receiving benefit from
*Indicates monetized metrics	

Table 1— Public Sector R&D Impacts

The importance of specificity cannot be over-stressed. This will increase the likelihood that the researcher is cognizant of whom the active players are in the area and who will be interested in, able to comprehend, and make use of the results. This is important in regard to competition, collaboration, dispersion, use of the results, and oversight considerations.

Step 3: Write a lay description of the objective of the research/technology project.

Writing for the lay audience (referring here to individuals who may not be scientists or engineers but are involved in allocating or administering research funds), heightens the awareness of the impact that agencies or organizations can have on research agendas and develops the capacity to address the concerns of this clientele, the purpose of this step. This awareness necessitates inclusion of a brief explanation or justification of government involvement in this research area.

The conventional explanation for government involvement in research and development is that, left to its own devices, the market would produce too little R&D because of externalities. (A good [product or service] is produced that is "public" in the sense that consumption by one individual does not diminish the quantity available for others (like a radio wave) and specific individuals cannot be excluded from consuming the good. When this is true, the market will not produce the good in optimal quantities. Examples include national defense or public health). A second circumstance justifying government participation is the presence of significant externalities. Externalities occur when benefits (or costs) from an activity spill out to third parties. In the case of R&D, private firms often have difficulty recapturing the benefits from their investments. Basic R&D produces diffuse benefits that are typically well removed from opportunities to recapture costs by marketing the results. Firms may undertake a small amount of basic R&D while the total benefits to society justify greater amounts. For more applications-oriented research, externalities may still occur. Government may also wish to stimulate more applied R&D to take into account specific types of external benefits such as improved environmental quality, quality of life, or energy independence. The brief explanation recommended here would explain the current status or relationship of public/private research in the area specific to the project.

Step 4: Chart the research plan, indicating on a yearly basis, the activities necessary to begin, execute, and implement the results of the research and development.

The purpose of this step is twofold. First, projecting the milestones for the research on an annual basis is necessary for the estimation of costs in Step 5. The identification or estimation of the date of market introduction is necessary for the calculation or estimation of benefits. Second, it will establish a plan to contact and obtain input and feedback from the individuals, especially ultimate end-users, identified in Step 1. This will incorporate follow-through for the adoption and use of the research results as an important part of completion of the project.

Step 5: Identify the positive or negative impacts of the research.

The purpose of this step is to record actual or estimated counts for R&D economy, technology/information, environment, and health/quality of life positive and negative impacts. The type of impacts to consider for inclusion should be derived from Table 1. Ideally, accurate data would be obtained for each category. In actuality, the available information is not that precise, certain, exhaustive, or unequivocal [7]. The profile of each research project will, therefore, include only the items for which data are available or can be reasonably estimated.

Step 6: Conduct a net present value or cost benefit analysis.

To conduct the analysis, all anticipated or actual research costs and benefits for both the government entity and all other collaborators should be projected on a yearly basis.

Costs

The feasibility of accomplishing the research objective within the time and resources allotted should be apparent after completing this step. As noted earlier, the concept of costs we are employing is the total cost of transferring the technology and, if appropriate, the total costs of resources uniquely associated with the acquisition of the innovation by the government laboratory. The type of costs to consider for inclusion should be derived from Table 1. Table 1, presumes, in its comprehensiveness, that perfect information is available. The standardization and thoroughness that are actually feasible, given normal conditions of imperfect information, are demonstrated in the two examples reviewed in Parts III and IV.

The cost to produce knowledge refers here to the investment made by the government laboratory to create or obtain expertise in a technology. It is measured by the sum of the costs of capital, equipment, and labor. For the laboratories, the fully burdened historical annual cost of the average scientific technical person at the laboratory includes operational R&D costs such as the cost of overhead for buildings, their maintenance, equipment, and purchases of incidental materials. This average annual cost is multiplied by the total number of scientific and technical persons involved in obtaining the targeted technology each year. The cost of the transfer of the technology to the private sector is measured by the amount of government and private sector investment allocated to the transfer. This can include grants, salaries, lodging, training, travel, equipment, facilities, and related costs.

The costs should be reported either as the sum of the cost of producing knowledge and the cost of the transfer or, if appropriate, as only the cost of the transfer. For example, the national laboratories are multi-program laboratories, with R&D programs in national security, energy resources, environmental quality, and industrial competitiveness. For some technology transfers, the cost of producing knowledge should all be allocated to the transfer. For others, for example those transfers of technology developed for a specific purpose such as national security, counting only the cost of the transfer may be a more realistic cost figure because the laboratory cost to produce the knowledge is often a sunk cost, unrelated to the actual transfer. It would have been incurred regardless of whether or not the transfer occurred, since the laboratory needed and used the knowledge for other purposes. (It is difficult and expensive to assess all of the sunk costs in defense research. In addition, all of the benefits derived from the investment in defense research are also difficult to trace since results are often published and dispersed widely, contributing to many different fields. If it were possible to trace the benefits of all research to all industries, the truest measure of impact could be derived. However, when data are publicly released and can be used without citation, it is impractical to produce a truly all-inclusive assessment of impact.) The benefit of national security and a viable defense were the intended and realized return on the investment made to produce the knowledge. Since there may often not be a valid basis to apportion a part of these sunk costs to the transfer, two numbers are calculated, one with these sunk costs included and the other with sunk costs excluded. This allows the evaluation audience to make the judgment based on full information.

Benefits

The three categories of benefits recommended for inclusion here are net profits, cost savings, and revenue from licenses or agreements. When R&D produces a new product or process, the license fees, the net profits and/or cost savings that accrue to the companies involved (e.g., if the government lab has a patent or copyright that is leased—revenue from these fees, the net profits from the sale of the product and cost savings realized when it is used), are tabulated in this step. This method aggregates this mix of benefits, without double-counting, from the firm, industry, and market level. Appropriate published data and industry experts should be consulted to estimate cost savings and net profits.

Once the monetized benefits are identified, the time period over which the benefits are estimated to accrue must be determined. The nature of technology is for it to be in continuous development. (For example, commercial impetus for the development of the transistor resulted from market pressures created by the discovery, refinement, and application of the vacuum tube. A bibliometric study might not make this connection, but a retrospective market research study would demonstrate this point. The institution that invented the transistor, Bell Labs, was actively searching for amplification devices that could improve upon the vacuum tube, which had become a big business). One technology can be said to "breed" another when it is replaced by its sequel. Thus, the lifetime of a technology extends from its discovery or invention through its market introduction, exploitation, and replacement by its sequel to when it becomes completely obsolete as a technology. The most complete and accurate investment appraisal or return on investment evaluation for a technology would be conducted from its market introduction to its point of complete obsolescence. Unless the point of complete obsolescence has been reached in a retrospective study, and therefore the actual lifetime is known, the recommendation here is to consult with experts in the field to obtain the most accurate lifetime estimate possible and then apply the following:

1. for technologies with estimated life spans of less than 10 years, the expert's best estimate,
2. for technologies with estimated life spans of more than 10 years: (a.) for technologies that are not revolutionary, set the benefit time period as 10 years; (b.) for technologies that are radically new, revolutionary in character, set the benefit time period as 20 years.

Although it may be valid to anticipate that a technology will continue and develop over more than 20 years, current convention in finance, accounting, and engineering economics is to limit forecasts, more commonly to five to 10 years, because of the uncertainty and unpredictability of the future.

Finally, the estimate of benefits needs to take into account the cycle of growth and decline of cost savings or net profits that will occur during the estimated market life of the technology. The analyst must define the total period over which the innovation will be successfully marketed, the distribution of total sales across this period, and the value of units sold. (A large number of studies have carried out similar calculations. For example, see [4, 5, 9]. For retrospective analysis, the researcher typically has a good deal of information on which to base an estimate of total benefits and their distribution over time. For example, data will likely be available on current applications of the technology, and current sales upon which forecasts of future sales can be based.

For prospective studies, in general, two types of innovations occur, those that are truly new and unique and those that are successive generations of an existing technology. For unique innovations, the analyst will, through consulting with experts, determine both the best case and worst case scenarios for what the potential market is if/when adoption occurs. The current adoption cycle of the current generation of the technology should be adjusted, employing expert opinion and other available data, to achieve the most reliable estimate possible.

The purpose of this step is to use a structured form of analysis to glean more information from the data gathered. The cost benefit calculation simulates the projection of net revenue employed by the private sector, but adjusts it to take into account the broader economic goals of the public sector. In particular, rather than netting revenues and costs, the public sector nets benefits and costs where benefits is a somewhat broader concept than that used in the private sector. Although the results of a cost benefit calculation can be provided in a number of different ways, the components of the analysis are the same (see Appendix B). Net present value is used here to aggregate costs and benefits.

Net present value is calculated in two steps. First, we convert the dollars in each year to a base year to correct for the fact that, because of inflation, the value of money changes over time and dollars from later years typically possess less purchasing power than values in earlier years. The GDP deflator series (base year is 1992) is widely available and is recommended for this purpose. Second, the constant dollars are then discounted to the year when funding for the research project under investigation began. This is done to recognize the fact that a dollar payable at some point in the future, say one year from now, is worth less than a dollar today. The difference between the two time periods is sometimes called the rate of interest or rate of return, but for present purposes we refer to it as the discount rate.

While there is no exactly correct discount rate, there are an almost infinite number of reasons put forth why discount rates should be higher or lower. In general, people who favor smaller government favor higher discount rates and those who favor larger government favor lower ones. In the US, the Office of Management and Budget sets rules for benefit cost analyses for government projects. The OMB has recognized this problem and issues an official discount rate in its A-95 circular. However, because the discount rate can significantly influence the calculation, it is often wise to bracket this rate to illustrate the sensitivity of the analysis to this choice. A bracketed or sensitivity analysis would, for example, use five percent and nine percent in

$$NPV = [(B0-C0)/(1+i)0] + ... +[(Bn-Cn)/(1+i)n) + T/(1+i)n]$$

addition to the current official rate of seven percent for i in the following formula:
where *C* represents all tangible costs, *B* represents all tangible benefits, where the time frame over which costs are incurred and benefits are received extends from 0 to *n*, the relevant rate of discount to equate future values to the present is represented by *i*, and where *T*, the discounted terminal value, captures any value of the project after its end date (such as residual or scrap value).

It is important to not disregard the other steps and place undue emphasis on the outcome of the cost benefit analysis. Some products of R&D do not penetrate economic markets in an easily traceable way, yet make important contributions to knowledge. If a positive net present value is important to the research project under investigation, a thorough assessment, regardless of the outcome of step seven, could be the foundation of later research, if anticipated costs and benefits change with time. Alternatively, it could prevent inappropriate future investment, if the concept resurfaces and conditions have not changed.

Step 7: Complete a technology impact profile report.

The purpose of this step is to create a standard format or convention to enable comparison with the same project over time and between projects. Following a brief description of how the projects were selected, the impacts for the two technologies are presented.

Case Selection

A time lag exists between the transfer of technology and evidence of its impact. To allow enough time for the impact of the transferred technology to be measurable, technologies were selected that had been transferred at least three years prior to the beginning of this study. (The transfers selected occurred prior to the increased emphasis on technology transfer. With the increased funding, planning, and support, subsequent transfers may achieve much greater impact.).

The total population of documented technology transfers at the time of the study from Sandia National Laboratories was well over 1,000. (If literature citations and more casual exchanges of data were included, the transfers would number in the many thousands. Source: SNL technology transfer official.) For the most part, the transfers are technologies from within the Laboratories' technical core competencies. The core competencies consist of four scientific research foundations (engineered materials and processes, microelectronics and photonics, computational and information sciences, and engineering sciences) and four integrated capabilities (advanced manufacturing technology, electronics technology, advanced information technology, and pulsed power technology [12]). Another classification for the Laboratories is in regard to the mode by which the transfers occur. For example, transfers occur through cooperative agreements, technical assistance programs, and publication of research findings.

A former manager of SNL technology transfer reviewed SNL technology transfers, choosing two transfers that met the following criteria: 1) successful transfers; 2) different from each other (in technology, transfer mechanism, type industry, time since transfer, etc.); 3) SNL maintained contact with the industries involved in the transfers; and 4) the industries would probably be receptive to participating in the study. The two selected were: plasma spray technology transferred to Fisher-Barton, Inc. and polycrystalline diamond drill bits transferred to the rock drill bit industry. The plasma spray transfer involves a small business, an industry less than 100 years old and the startup of a new small business. Thermal spray is within the engineered materials and processes core competency and the transfer occurred through a DOE technical assistance program for small businesses.

The polycrystalline diamond drill bit transfer involves small, medium, and very large businesses, an industry more than 100 years old, and robust competition. Polycrystalline diamond drill bit technology is within the engineered materials and processes core competency, but is also very interdisciplinary including technologies from the computational and information sciences and engineering sciences (mechanical design and fluid mechanics) core competencies. This transfer occurred through industry advisory committees and industry and university research funded by SNL.

Case Study 1: Thermal Spray

Table 2 represents the impact of the plasma spray technology transfer from Sandia National Laboratories to Fisher-Barton, Inc. in regard to health, economy, and technology/information. Indicators in three categories contribute to a very positive impact profile for this research project. Particularly in regard to economy and technology/information, the indicators show that the transfer fostered productive, sustainable growth. TST is currently engaged in many activities and projects to develop new products and processes. Because of confidentiality concerns, these were not reported here, but could be reevaluated in the future to enable a more complete and accurate assessment of impact.

The Fisher-Barton case is an excellent illustration of successful collaboration between a very large government laboratory and a small company. Despite some inherent disadvantages, including limited capital and slack resources, small companies are, in some ways, ideal candidates for working with government laboratories. The decentralization and flexibility of the small company often contribute, as here, to the success of collaborations. Often, a small company competes on the basis of innovation and, thus, has a vital stake in the transfer, as well as great commitment. Research has demonstrated that smaller firms are more likely to develop commercial products from their interactions with government laboratories [1].

Case Study 2: Polycrystalline Diamond Drill Bits

Indicators in four categories (Table 3) contribute to a very positive impact profile for this technology transfer. Particularly in regard to economy and technology/information, the indicators show that the transfer fostered productive, sustainable growth. SNL is currently engaged in research to advance the efficiency and effectiveness of PDC drill bits, further increasing the benefits that will be derived by society from this technology. (One recent example being the report from BP Exploration Co. (Columbia) Ltd. that in drilling in Columbia's Cusiana field, one PDC bit saved $419,000 [11]).

The impact profile for the polycrystalline diamond drill bit technology transfer is a success story. The contribution that Sandia National Laboratories made to the oil and drilling industries is considerable. In many respects the PDC bit case is an ideal example of the way public R&D should" work. The government initially got involved in PDC bits because of market failures associated with geothermal drilling technology and government priorities for energy resources. SNL management had the foresight to examine from a systems viewpoint all aspects of energy availability from discovery through production and final use of energy supplies. This led SNL to emphasize areas where industry had identifiable technical problems to be solved. Both SNL and industry could effectively work on the same problem and satisfy two very different sets of needs, serving the public good and increasing the efficiency and profitability of industry.

In collaboration with industry, the early review of the industry's technological needs, the targeting of specific technologies, and the setting of specific R&D goals provided direction uniquely available through the combination of the Laboratories' concentration and depth of scientific expertise in conjunction with the Laboratories' perspective—external to industry. The capacity to provide funds to sustain industrial R&D was also a contributing factor to this transfer's success. Technology was transferred into the public domain and widely used. Commercial benefits accrued precisely because knowledge was freely available. The collaborative spirit and free flow of knowledge are striking features (occurring as they did in a very competitive industry) of this transfer.

This case stands in marked contrast to the Fisher-Barton case, not so much in the quantity of benefits, as in the distribution of benefits. In the drill bit case, the benefits were distributed quite broadly and the flow of knowledge was less hand-to-hand. While the diffuseness of the benefits presents some problems for evaluators, it is an equally valid approach to technology transfer and one that is particularly likely to lead to impacts of great magnitude.

ECONOMY	
POSITIVE IMPACTS	
Business Startups	1
Jobs created	10
Successive Business Users	6
*Cost\Benefit ratios (cost = knowledge production and transfer costs)	
@ 5%	1:4
@ 7%	1:4
@ 9%	1:3
* Cost\Benefit ratios (cost=transfer costs)	
@ 5%	1:274
@ 7%	1:229
@ 9%	1:193
TECHNOLOGY/INFORMATION	
POSITIVE IMPACTS	
new patents	1
new publications	4
citations new publications	5
industry trainee (number of)	1
industry trainee (number of months)	15
follow-on research projects	1
HEALTH/QUALITY OF LIFE	
POSITIVE IMPACTS	
percent of population receiving benefit from transfer	50%
*monetized metrics	

Table 2 — Plasma Spray Impact Profile

ECONOMY	
POSITIVE IMPACTS	
Jobs created	475
Successive Business Users	4
*Cost\Benefit ratios (cost = knowledge production and transfer costs)	
@ 5%	1:37
@ 7%	1:33
@ 9%	1:30
TECHNOLOGY/INFORMATION	
POSITIVE IMPACTS	
new publications	34
citations new publications	68
new computer algorithms/software	2
incremental product improvement	1
successful problem solving	2
follow-on research projects	1
HEALTH/QUALITY OF LIFE	
POSITIVE IMPACTS	
percent of population receiving benefit from transfer	100%
worker accidents prevented	3260
worker fatalities prevented	36
*monetized metrics	

Table 3 — Diamond Drill Impact Profile

This article began by acknowledging the increasing pressure to justify further funding of public sector research and development. Justification and optimization of public sector research and development will be better realized when the impacts of both completed and proposed projects are accurately and thoroughly reported. The fullest accounting of R&D may not be accomplished until a decade or two after the completion of the project, so it is important to plan to conduct both retrospective and prospective analyses to satisfy the need for greater accountability and efficacy in public R&D. Research scientists should recognize that well done evaluation will most often be a positive marketing tool, perhaps even a necessity for earning the privilege of conducting research and that the ultimate goal is to clearly identify the impact of technology transfer from their laboratories in a manner that can be useful in the resource allocation process.

Generally, the impact profile evaluation method is sound for assessing costs and benefits accruing from technology transfers, based as it is on standard assumptions of a well known and widely-applied set of cost-benefit analysis principles. However, the following issues need further consideration: the validity of experts' estimates, the sequence of profile preparation, the choice of indicators, the cost calculation, the boundaries of the transfer, and the economic contribution of knowledge.

In many instances, the application of the method will require the use of experts' estimates. The nature of retrospective analysis is such that either the type of financial and nonfinancial data needed was either not recorded in the first place, not published, or records are no longer available. If this type of assessment were to become more routine, records that would facilitate its execution might be more commonly maintained and filed.

For future impact profiles, the more efficient sequence of impact profile preparation is to first spend sufficient time up front to understand the technology and to obtain all available information from published sources. The next important step is to use this understanding and information to ensure that, if at all possible, the specific indicators for which data will be sought for the profile and appropriate scales of measurement are identified and compiled into standardized questionnaires specific to the sector (ie., a questionnaire for each type of industry involved, for SNL managers, for university scientists, etc.). If these two steps are taken prior to interviews with experts, the interviews will be more efficient.

Progress was made toward identifying what the parameters of an assessment (choice of indicators) of the impact of transferred technology might be. Yet, questions remain whether the four areas are comprehensive or narrow enough, whether the measures chosen within each area are appropriate and sufficient, and whether there can be any uniformity between the scales of the measures from one technology transfer to another. As was intended, the two transfers were different enough to pose singular issues in regard to the measurement of each indicator. This method can provide a point of departure for the R&D evaluation community to move toward identifying what the areas of greatest importance are, what should be measured, and what acceptable practice in measurement might be.

While there can be no simple recipe for conducting impact studies because the technologies and industries differ greatly, impact profiles provide a framework to guide future studies. It is important, as far as possible, to provide common points of comparison and to encourage that current projects be archived in ways to facilitate future research on impacts.

The great range in return-on-investment indicators is chiefly owing to different approaches to calculating costs. Clearly, there is no one-best-way. It is vital, however, that one be aware of the great differences depending upon cost calculation. A primary concern, in the case of technology transfer impacts, is the extent to which one "charges" as a cost, the amount spent on the direct mission objectives of the laboratories. In all likelihood, the most sensible approach is to develop some type of discounted overhead investment figure to use in the calculations. This will require further research and more information about laboratories' accounting and overhead.

In a more direct, hand-to-hand transfer (e.g., Fisher-Barton, Inc.), the setting of boundaries is not troublesome. But in more diffuse transfers, the parsing out of credit remains a problem. It is difficult to know just where the benefit lines should be drawn. The best approach, perhaps, is just to make sure one is clear in communicating assumptions.

Each transfer examined here yielded not only tangible economic benefit but a stock of knowledge as reflected in the technology /information area. Arguably, that contribution is not fully captured by examining the economic use to which the information is put. The economic benefits are understated by the lack of quantification of the contribution of knowledge in dollar values. In the first place, the information may have inherent value beyond its economic use. Second, the economic appropriation of the information may occur at various points in time by various parties, including, perhaps, some in the intermediate-range and distant future. There is likely to always be an undercounting of the benefits of any scientific and technical knowledge not subject to immediate and direct appropriation.

Collaborative research (consortia, partnerships, etc.) among government, university, and industry laboratories is a component of the R&D system that embodies the synergy of R&D in an institutional form. In both official and unofficial collaborative interactions, the goals and orientation unique to each sector can enhance the timeliness, creativity, and thoroughness of the research. In this study, a high degree of synergism was observed between the laboratories, industry, and universities. The diversity represented by these elements is important to preserve and further encourage. As the laboratories start to work increasingly with industry, questions of fairness and equal access become more pressing. One way to enable fairness is to foster consortia that enables entire industries to benefit. In a sense the PDC drill bit transfer fits this model, although no formal consortia existed. In future studies it might be appropriate to include an early formal consortium.

However, an alternative viewpoint of consortia held by some researchers is that it is a good theory that only works well in rare cases for the following reasons. Positive aspects of consortia include: a broader constituency enabling a broader base of support; more productive for precompetitive research; foster breakthrough research if participants are committed and agree on licensing; more stable over time; and it is less subject to criticism of unfairness or advantage to one firm. Negative aspects of consortia include: extremely time-consuming and difficult to form because of cost; resistance because of competitiveness pressures; unwillingness to assign top researchers to work on; unwillingness to work on cutting edge technology because of competitiveness pressures; and unwillingness to make time (long term) and effort commitments. In contrast, individual companies in partnership agreements with the laboratories anticipate greater and more exclusive return and therefore commit resources more willingly and effectively.

Appendix A

The US Department of Commerce's Bureau of Economic Analysis (BEA) has provided published multipliers, listed by state, available at no cost and will calculate multipliers for specific industries in specific counties or regions on a fee basis. If budget and time restrictions apply, the published Regional Input Output Modeling System (RIMS II) input output multipliers could be used. Although the published multipliers are not as current as those obtainable for a fee, they are reasonable and conservative for the estimation of the regional economic impacts of the introduction of a new technology.

Appendix B

The following example is included to illustrate one alternative method (to cost benefit analysis) of calculating R&D economic impact. Consider an electric utility faced with a choice of either purchasing "scrubbers" to remove sulfur from stack gas emissions or purchasing "emissions permits" that give the utility the right to emit one unit of sulphur per permit. Assume that the utility's process normally emits 100 units of sulphur and that it must use one permit for each unit over 15 that it emits. Assume further that permits can be purchased at a constant cost of $10 per permit, or $850 if the firm wanted to rely strictly on permits. Scrubbers each reduce stack gas emissions by one-half. Hence, the first scrubber reduces emissions from 100 units to 50 units, the second to 25 units, and the third to 12.5 units (below the threshold of 15). For the present, assume that each scrubber costs $80. The utility thus compares the cost of buying scrubbers with that of buying permits. For $240 it can meet its emissions reduction responsibilities by buying three scrubbers. Moreover, it saves $610 by doing so. Using these assumptions no combinations of permits and scrubbers would yield greater savings.

Note that the value of the scrubbers to the utility is significantly different from their costs. The first scrubber reduced sulphur emissions by 50 percent, yielding a savings over permits of $420 ($500 - $80). The firm would have been willing to pay up to $500 for the first scrubber given its alternatives but did not need to do so. The second scrubber reduced sulphur emissions by 25 percent with a savings of $170 ($250- $80). Again, the willingness of the utility to pay for the scrubber was up to $250. The third scrubber reduced emissions by 12.5 percent, for a savings of $20 ($100 - $80; note that the emissions requirement was 15 necessitating a purchase of only 10 permits). Overall, a savings of $610 occurred. This value is sometimes termed consumer surplus. In this example, the demand derives from the nature of the scrubber technology and the price at which permits can be purchased. For a household considering a similar decision, it would be necessary to calculate the household demand function to estimate willingness to pay.

In general, the net benefit, otherwise known as consumer surplus, accruing to an innovation is measured by difference between the willingness to pay (expressed by the current cost of the least cost substitute) and the actual cost of the innovation (assuming that it is produced at constant rather than increasing cost). Were the target of analysis an entirely new product for which there are no substitutes there would be no alternative but to calculate the demand function for the innovation, a difficult task. Fortunately, when there are close substitutes, as scrubbers and permits, the cost savings (net benefit or consumer surplus) can be approximated much more easily.

Suppose, in this case, a new alloy reduced the cost of the scrubber by $20. Thus, the annual savings from the innovation would be $60, $20 each for three scrubbers. By estimating the overall number of scrubbers purchased and the effective "life" of the innovation, a present value for the innovation could be calculated. Note that by design, this example yielded an easy calculation. If the scrubber originally cost $110, rather than $80, the firm would have only purchased two scrubbers and used permits to achieve the remainder of its emissions target. If a cost saving innovation reduced the cost below $100 (the cost of permits), the firm would purchase three rather than two scrubbers. Suppose that the innovation reduced the cost from $110 to $90. Then the savings would be $40 from the first two scrubbers and an additional $10 from the third scrubber. In general, the bench scientist will not know the exact demand curve and will therefore not calculate an exact benefit (the values will be approximate). However, if substitutes exist for the innovation, we believe this approach approximates the savings well enough for the purpose at hand.

Whenever a process innovation occurs that lowers the cost of producing a product, this method provides a close approximation of the net benefits up to the point at which the lower costs attract additional purchases, and there is no need to estimate a demand function. In the case above, the process innovation improving the scrubber only affected cost and hence willingness to pay for the old scrubber and the improved scrubber was identical. Hence, willingness to pay for the two types of scrubbers nets out and benefits are estimated as reduced costs. For virtually all process innovations and most product innovations, net benefits can be calculated in this manner as a close approximation. ◆

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