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Benefit-Cost-Analysis & Tracing Innovation

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Preface

The motivation for this newsletter and a workshop which was held in Vienna in late December 2007 was to bring in new methodological ideas in the R&D evaluation discussion. For this purpose, Platform fteval picked two methods: first, Cost Benefit Analysis (which nowadays, after a relaunch of the methodological brand, is called "Benefit-Cost-Analysis & Tracing Innovation") and second, "tracing innovation".

Both methods are not "new": The US looks back on a long tradition in using this method to evaluate R&D programmes, and is used outside the innovation and R&D community quite broadly. Tracing back innovation with patent citation analysis is an up-and-coming method as presented here, but again working with patent data has a long tradition. So, why our interest? Both methods are "new" in the context of Austrian R&D evaluation, and to some extent new for a lot of other European countries. So it is worth having a close look on it and discuss methodological pro's and con's.

The newsletter starts with a general overview on Evaluation Methods for R&D programmes (Rosalie Ruegg). Rosalie gives a brief overview of evaluation methods and presents a guide for selecting among them which could be most interesting for the dialogue between evaluators and those commissioning evaluations.

Jeanne W. Powell introduces benefit-cost analysis and discusses its advantages and disadvantages. She presents ATPs (Advanced Technology Program) experience with this tool and draws attention to cluster analysis, which "extends benefit-cost analysis from a single project to a broader segment of a program's portfolio" (Powell)

By means of his Photonics cluster study Thomas Pelsoci shows a case example of benefit-cost analysis and describes main criteria of such an analysis (clear, transparent, and credible; grounded in an essential understanding of the new technology and the prior state of the art; must reflect a sufficient understanding of the industries and markets). In his article, Tom demonstrates how analytical results can be utilized.

Rosalie Ruegg and Patrick Thomas illustrate tracing innovation with an example from the U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE) Program and show how advanced patent citation analysis techniques can be used to identify "hot" patent and "next generation" patent analysis.

Beside its main topic on BCA and tracing innovation, this newsletter presents two more articles.

Barbara Birke introduces an external quality assurance (Quality Audit) procedure that provides support to universities in the development of their quality management systems and discusses her experiences with Benchmarking Procedures within the Quality Audit procedures.

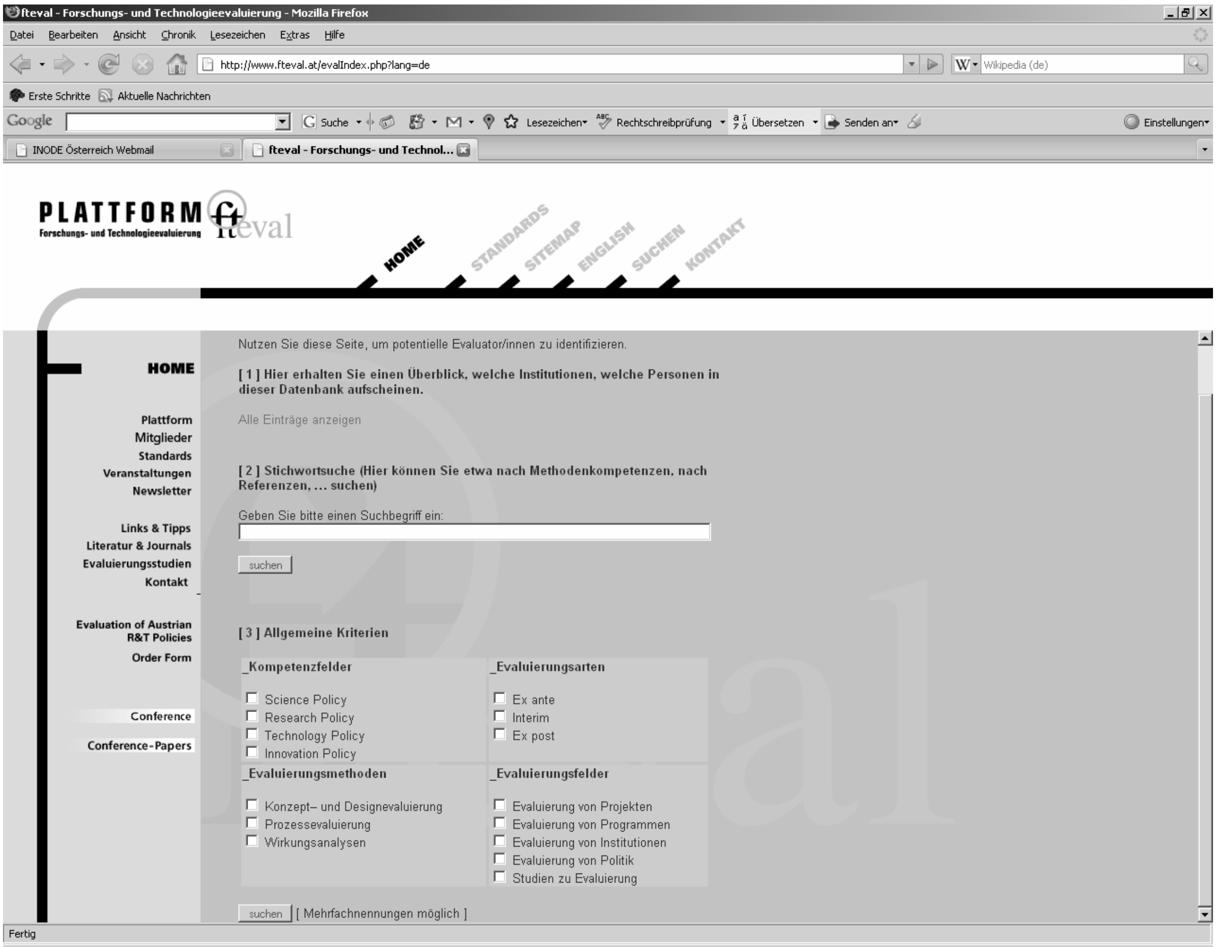
Finally, let me draw your attention to a piece of work done by the European Court of Auditors. Martin Weber and Gareth Roberts discuss the European Court of Auditors' audit of the Commission's evaluation system for the Research and Technological Development (RTD) framework programmes. This article briefly describes the EU RTD framework programmes and their evaluation and provide an insight into the European Court of Auditors' Special Report 9/2007 concerning the European Commission's system for evaluating the EU RTD framework programmes. Martin and Gareth try to emphasize the important role that should be played by robust programme evaluation, which was also highlighted by the audit.

News from our homepage: In the last couple of weeks we improved our homepage www.fteval.at. Now you can find a download facility of our publication "Evaluation of Austrian Research und Technology Policies. A Summary of Austrian Evaluation Studies from 2003 to 2007".

Additionally we created a databank for evaluators, with the intention to give an overview of evaluators in the field of research, technology and innovation policy in Austria.

To identify potential evaluators, you can browse all listings or search for evaluators according to the following criteria: (See screenshot 2)

- Area of Competences
- Type of Evaluation
- Methode of Evaluation
- Field of Evaluation



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Rosalie T. Ruegg

Evaluation Methods for R&D Programs

R&D program managers, while knowledgeable about their programs, may not know how best to assess program performance. There are a number of questions that they may need to answer and multiple evaluation methods from which to choose. Here we present a brief overview of a directory of evaluation methods and guide for selecting among them that was prepared especially for managers of R&D programs. The referenced directory provides an overview of 14 evaluation methods that have proven useful to measuring R&D program performance, and a "roadmap" on how to select among them.[2] Three of the methods introduced here are discussed further and illustrated in two papers in this issue: Benefit-Cost Analysis and Tracing Innovation.

WHY EVALUATE AND WHY USE MULTIPLE METHODS?

Evaluation helps to guide program management and strategy by determining how a program is performing, whether there are performance problems or problems with operational efficiency, and if adjustments are needed. Evaluation also is used for accountability. Is the program doing what it was intended to do? Is it worth continued support—at the same level? At a reduced level? Are fundamental design changes needed?

Multiple methods are useful for at least three main reasons: to answer the different questions stakeholders ask; to provide alternative perspectives; and to provide multiple lines of evidence of results.

HOW TO DEVELOP AN EVALUATION STRATEGY?

Developing an evaluation strategy begins by determining your specific evaluation needs—specifically by asking *who* needs to know *what* and *when. Who* may include program staff, senior managers, policy makers, budgetary authorities, and other stakeholders. *What* may include information about progress against targets, about how to improve outcomes, about long-

[2] For the full directory of methods, see Ruegg and Jordan, *Overview of Evaluation Methods for R&D Programs; A Director of Evaluation Methods Relevant to Technology Development Programs*, March 2007. This introduction is based on the Directory and draws on a demonstration of it by Ruegg and Jordan at the American Evaluation Conference, November 2007.

term impacts, and about need for changes in strategy. *When* may be a prospective look at investment decisions, or it may be a retrospective look in the short term, in the intermediate term, or in the long term of outputs, outcomes, and impacts.

It is recommended that you consider your evaluation strategy in the context of a “logic model” of your R&D program—a graphical depiction of how your program is structured to meet its mission by undertaking specified activities intended to achieve certain results, and in terms of the questions that tend to arise at the different stages typically covered by a logic model. The referenced directory contains an illustrative logic model and a coordinated set of four tables, corresponding to each of four phases of a program’s performance cycle, which flesh out the questions that are typically raised at each phase. The tables link each question to one or more evaluation methods contained in the directory. (The logic model and corresponding tables are not shown here.)

BRIEF OVERVIEW OF EVALUATION METHODS

How an evaluation study is designed is dependent on the type of question asked. Three common categories of questions are (1) descriptive questions, (2) normative questions, and (3) impact, or cause-and-effect, questions. Over time, a group of evaluation methods have been used sufficiently to become recognized as acceptable ways to address the kinds of questions commonly asked by program managers and policy makers. Over time, additional methods are being developed and existing methods refined; thus, the field is far from static. Here we provide a very brief overview of a number of evaluation methods. [Fuller definitions, descriptions, explanations of how each method is applied, discussions of its limitations, its practical uses, and examples of its use are provided in the referenced directory.]

Peer Review/Expert Judgment

This widely used method encompasses qualitative review, opinion, and advice from those knowledgeable of the subject being evaluated, based on objective criteria and sometimes informed by quantitative evidence. It is used in evaluation to assess such things as research quality, researcher and organizational productivity, feasibility of goals, levels of risk, and degree of program success.

Monitoring/Tracking of Activities, Milestones, and Outputs

Monitoring a program as it is carried out—collecting data, generating metrics to indicate interim progress, problems, and the need for corrections, and building a database to support longer-term evaluation—is integral to program evaluation, and, hence, is included in this listing of methods. Ideally informed by a program logic model, program monitoring/tracking compiles data on key activities, program participants, and program outputs and outcomes. These data can be used to analyze program progress toward meeting objectives and to provide quantitative indicators of interim performance, both for program management and accountability.

Bibliometrics

Bibliometric methods are text-based approaches used to show that knowledge has been created and disseminated. They are used to show the emergence of new ideas and development of the paths through which these new ideas have effect. There are a set of techniques that fall within the bibliometric category: (1) Counting publications and patents provides measures of knowledge outputs of a program. (2) Citation analysis focuses on knowledge dissemination, and may be performed backward to find linkages from an innovation of current interest to past-generated knowledge, as well as forward to find the influence of a research program's knowledge creation on down-stream outcomes. (3) Advanced techniques in citation analysis such as "hot" patent analysis and "second-generation" patent analysis are used to identify higher value patents, while "aggregate citation analyses" can be used to assess the significance of patent outputs at the organizational level. (4) Data mining is used to extract key concepts or relationships from large quantities of digitized natural language text for the purpose of identifying the origin and further development of key ideas and concepts and the emergence of relationships among research organizations and disciplines. Each of these is a stand-alone technique; their commonality if that they are based in the written word.

Historical Tracing

The historical tracing method identifies and documents linkages from R&D to downstream outcomes, or, alternatively, from a target innovation back to the underlying R&D. It uses interviews with experts, document review, and, increasingly, citation analysis (as described above) for tracing linkages. While historical tracing often uses citation analysis as a valuable tracing tool, it provides a broader picture of developments than citation analysis used alone because it takes into account linkages that are not captured by citations. Historical tracing is used to provide evidence that research programs underlie innovation, to show and explain the complex paths that typically characterize the processes by which research spawns innovation,[3] as well as for other purposes. [See the paper in this issue, *Tracing Innovation*, for an example of historical tracing used together with patent citation analysis to trace linkages between battery and ultracapacitor technologies for hybrid and electric vehicles and upstream research in energy storage for vehicles funded by the U.S. Department of Energy.]

[3] It should be acknowledged that innovation can also spawn research.

Network Analysis

Network analysis develops diagrams of knowledge-flow connections among people and organizations, designating the researcher or organization as "nodes," the flows between entities as "links," a sequence of links from one node to another as a "path," and showing the direction of the relationships by arrows. Network shape, size, and density can identify communities of practice and signal relative roles and relationship and the extent, strength, and dynamics of collaboration. Network diagrams constructed at different points in time can show changes in the nature of networks over time. Among other things, network analysis is useful for analyzing the impact of R&D policies on collaborative activity for analyzing the relative positions of researchers and organizations, and for assessing the robustness of social systems.

Case Study

Case study describes, explains, and explores phenomena and events. It can tell the story of research; it may explain the what, why, and how of research, investigate underlying relationships, and help form hypotheses for further exploration using other methods. Case studies "put meat on the bones" of statistics and can deepen stakeholder understanding of a subject. Information used to develop a case study often comes from interviews, direct observations, existing databases, and literature searches. A shortcoming of an individual case study is that it is considered anecdotal and does not yield results that can be generalized.

Survey

Survey is a widely used method that asks people questions, records and codes responses, aggregates results, analyzes the data, and reports and displays results to describe a program statistically, show trends, rate customer satisfaction, and generate performance measures. If a survey is correctly designed, survey results may be generalized to a population.

Benchmarking

Benchmarking means systematically comparing some aspect of a program, institution, region, country, or other entity against counterparts or against established standards or targets, using selected performance measures. For example, organizations may be benchmarked with respect to their R&D budgets, productivity, skill sets, technical prowess, selected outputs, and other dimensions. Such comparisons show relative standing and, for example, may identify weaknesses where improvements are needed, as well as comparative strengths to be preserved.

Benefit-Cost Analysis

Benefit-cost analysis estimates in monetary terms the positive (benefits) and negative (costs) effects of a project, cluster of projects, or program. It relates benefits to costs, providing measures of net benefits, benefit-to-cost ratio, and internal rate of return on investment. For public R&D programs, the emphasis is on social returns and returns to the public investment rather than on private returns. [See the papers in this issue by Powell and Pelsoci for additional description of the method, a step-by-step guide to a performing an analysis, and for an example of a benefit-cost cluster study performed for the U.S. Advanced Technology Program.]

Technology Commercialization Tracking

This method was developed by the U.S. Department of Energy for its internal monitoring of the commercialization success of its energy-efficiency technologies and estimation of direct energy savings, environmental benefits, and cumulative net benefits of the program. This method, with its focus on commercialization, classifies the program's technologies by the extent of their commercial development, using such categories as "emerging," "commercially successful," "mature," and "historical."

Econometric Methods

This is a broad category encompassing multiple mathematical and statistical techniques used to capture relationships between R&D investments and changing economic, technological, and social phenomena. These methods include production-function and cost-function models. Production-function models, for example, have been used to measure the impact on firm productivity of participating in government-funded research; cost-function models have been used to estimate market spillover benefits. Econometric methods are highly quantitative, and data availability and compilation are integral to model building. They offer rigor of estimation, but may be complex and difficult for the non-specialist to understand and use.

Spillover Analysis

Spillover analysis is not a method per se, rather it is a goal of analysis—to measure effects that are external to, and not captured by, the investor. "Research spillovers" may include "knowledge spillovers," i.e., knowledge captured by others without paying; "market spillovers," i.e., increased uncompensated value in new and improved goods and services that are captured by consumers and by producers; and "network spillovers," i.e., increased uncompensated value to holders of existing goods and services attributable to complementarities provided by a new technology. Positive research spillovers increase the value to society of innovation; failure to consider them can result in underinvestment in research from a societal standpoint. Measuring spillovers is challenging and has been performed with more than a single method. Most existing spillover studies focus either on knowledge spillovers using bibliometric and networking approaches, or on market spillovers using a benefit-cost framework or cost-index approach, but few studies have measured both knowledge and market spillovers, and few have focused on network spillovers.

NEXT STEPS

This brief introduction to evaluation methods for research programs provides context and perspective for going deeper into evaluation, as well as an introduction to the three methods treated in subsequent papers in this issue: benefit-cost analysis, historical tracing, and citation analysis. The papers by Powell, Pelsoci, and Ruegg and Thomas provide examples from the U.S. of how these three methods are used. This introduction also calls your attention to the Directory of Evaluation Methods (referenced below) as providing a quick reference source for more information on all of the methods introduced here, including a guide to using them and more examples taken mainly from U.S. practice.

References

Ruegg, Rosalie and Jordan, *Overview of Evaluation Methods for R&D Programs; A Directory of Evaluation Methods Relevant to Technology Development Programs* (Washington, DC: U.S. Department of Energy, Energy Efficiency and Renewable Energy, March 2007 http://www1.eere.energy.gov/ba/pba/program_evaluation/evaluation_documents.html.

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Benefit-Cost Analysis: Overview

This paper provides an overview of basic benefit-cost analysis methodology, drawing on examples from the Advanced Technology Program (ATP). In the context of evaluation of government-funded R&D projects and programs, it presents the key concepts and discusses the advantages and disadvantages of benefit-cost analysis. It provides a 10-step methodology. It summarizes ATP's experience with this tool and introduces cluster analysis, which extends benefit-cost analysis from a single project to a broader segment of a program's portfolio.

Benefit-Cost Analysis: What is it?

It's an evaluation tool. Historically, it gained widespread use in the evaluation of U.S. government water projects in the 1930s. Since then, it has become more broadly used by U.S. programs—for example, for programs involving transportation, public health, and the environment—earlier mainly prospectively to assess the net impact of a policy change or major new program investment, and, more recently, retrospectively for program management and accountability.

Our interest is in evaluation of publicly-funded R&D projects. As applied to program evaluation of publicly-funded R&D, benefit-cost analysis estimates the net *impacts* of an R&D project or group of related projects *in monetary terms*. The analysis aims to measure impacts against the program mission; i.e., what the program is designed to accomplish. It should be consistent with impacts defined in the program's logic model and its timeline for impact. Being R&D, the timeline to impact is likely to be fairly long and therefore measurement of realized benefits will likely be relatively long term.

The analysis will compare total estimated benefits from undertaking an R&D project measured over a defined study period with the R&D investment costs. Technically, the analysis is likely to be most useful if it is substantially retrospective, although it may be prospective or a combination of the two.

What type of evaluation tool is it?

What does a benefit-cost analysis look like? What is it good for?

It is a quantitative case study.[1] It may be combined with and nicely complement a qualitative, descriptive case study. The quantitative analysis is based on monetary valuation of multiple types of economic benefits resulting from the R&D project expressed as cash-flow analysis.

It is generally most suited to long-term evaluation. Risks and uncertainties of R&D are large in early R&D phases; therefore the probability distributions of the economic estimates are broad until technical and business uncertainties are reduced in the longer term. Economic estimates are likely to be most useful once major sources of uncertainty have been diminished. As a result, a benefit-cost analysis is generally most suited to applied R&D that is relatively close to market.

What does it measure?

It measures *return on investment.*

The three most common metrics are: *net benefits*, or benefits less investment costs; *benefit-to-cost* ratio, or the benefits per dollar invested; and *internal rate of return*, or the discount rate that equates time-adjusted benefits to investment costs.

Whose Return?

Benefits to whom? Investments from whom?

For our purposes, envision an R&D project conducted by private industry but partially funded by a government program. For program evaluation purposes, there are two different approaches that can be applied.

1. Social Return analysis

This approach is grounded in the research on social and private rates of return from corporate R&D published by Dr. Edwin Mansfield of the University of Pennsylvania in the early 1970s and subsequently adapted to econometric analysis by Zvi Griliches and others. These combined efforts provide empirical support for growth economics.

The social rate of return is the combined rate of return to R&D participants and to society broadly on the total R&D investment (all sources). The social return has two components:

[1] For more information on benefit-cost analysis in comparison with other evaluation approaches used by the Advanced Technology Program, see Ruegg and Feller, *A Toolkit for Evaluating Public R&D Investment: Models, Methods, and Findings from ATP's First Decade* (Gaithersburg, MD: National Institute of Standards and Technology, July 2003)

- private return is the return to project participants. The innovator is focused on the return on the innovator's own investment. It represents the profit from commercializing successful R&D relative to the innovator's investment in the R&D. This is the measure that a financial analyst/banker/venture capitalist would compute. More relevant to social return analysis is the return to project participants on combined sources of investment.

- spillover return is the return to others beyond the participants; i.e., to customers of commercialized R&D and to society broadly, on combined sources of the R&D investment.

2. Public return analysis

This approach focuses on the *increased* social return enabled by the government investment relative to the government investment. We'll call it *public* return to differentiate from the spillover component of social returns. Public return analysis specifically measures the additionality effect of the government funding. It can include both private and non-private components in that government funding may result in increased private benefits and increased benefits to downstream technology users and society broadly.

ATP has focused on public return analysis—and has placed less emphasis on private benefits from the calculation in accordance with ATP's mission of broad-based economic benefits to the nation.[2]

Advantages of Benefit-Cost Analysis

Benefit-cost analysis provides quantitative estimates of impact that complement qualitative case studies and anecdotal case studies. The metrics are based on standard financial analysis used by private businesses. The metrics are therefore intuitive and relatively easy to understand. Although the models used are more complex than return on investment models used by the private sector (the public finance literature has extended private return models to the analysis of broader social benefits), they can be applied systematically and relatively uniformly.

[2] For a more in-depth discussion of methodological issues in applying benefit-cost analysis to program evaluation of government-funded R&D, including application of public return versus social return approaches, see Powell, *Toward a Standard Benefit-Cost Methodology for Publicly Funded Science and Technology Programs,* NISTIR 7319 (Gaithersburg, MD: National Institute of Standards and Technology, June 2006).

Data requirements are less for benefit-cost analysis than for statistical or econometric evaluation approaches that might be used alternatively for measurement of program impacts over the longer term. Data is gathered from structured interviews with funded companies, their customers, and other technology and business experts—rather than through surveys.

Results of benefit-cost analyses are easier for policy makers to understand than those based on dynamic macroeconomic impact models or other econometric models. ATP has done several studies that applied the REMI macroeconomic model and a hedonic price index model. Both required more historical industry data than are available for most ATP-funded "new" industries, and the models seemed to evoke skepticism as "black box". (Examples of ATP's use of the REMI model are the two 2mm project studies conducted by MIT and CONSAD and the flow-control machining study conducted by NIST's Building and Fire Research Laboratory. The digital data storage study conducted by RFF and a portion of MIT's 2mm study are examples of the application of hedonic price index models. These studies are all available on ATP's website. See Table 1 and www.atp.nist.gov/eao/eao_pubs.htm.)

Disadvantages of Benefit-Cost Analysis

There are plenty of difficulties! Modeling of spillover benefits is challenging and not inexpensive. Many important spillover/public benefits may be difficult to express in monetary terms.

Private benefits are often confidential/company proprietary. The closer their R&D is to a commercial product, the more hesitant companies are to talk about sales volumes, prices, costs, and profits. As a result, in many cases, it is not possible to obtain good estimates of private returns.

Nevertheless, good sales volume information is needed for estimating public/spillover returns as well as private returns. Companies are somewhat more willing to provide this information than profits; however, they tend to provide more optimistic estimates of expected future sales than can be deemed credible. It is necessary to combine company-derived information with interviews of various types of industry experts to obtain fair and reasonable estimates of projected sales volumes.

Summary of Advantages and Disadvantages

Benefit-cost analysis is a *practical choice* for long-term evaluation of program impacts; however, one should not be in a hurry to apply it to a given project!

The technical risk associated with R&D projects is, of course, a major issue in prospective analysis. Government funding (even combined with other funding available) may get a project only part way toward its original planned technology outcome, or the technology may come to a bend in the road and pursue a different path entirely than originally anticipated.

Entrepreneurial challenges, market adoption of new technology-based products, and diffusion of the technology to the spectrum of product applications enabled by many technologies entail similar risks and uncertainties. Although companies developing and promoting their technologies need to be optimistic in order to be successful, actual experience indicates that even technologies ready for market, and with some initial signs of market interest often fail; e.g., for lack of financing or just customer fear of "change". Others succeed only in very limited, low impact applications.

ATP has a considerable database documenting such expected outcomes from its continuous survey of its portfolio of awardees. This history indicates that expected value of estimates of cash flows used in prospective benefit-cost analysis need to reflect considerable likelihood of estimation error. The utility of the analysis will likely increase as the empirical basis that accompanies actual, realized benefits increases and as estimation errors associated with incomplete technical development, product development, financing, market adoption, and economic diffusion decrease.

As a practical matter, the analysis probably will not wait for full resolution of uncertainties. The technology trail will grow cold in the meantime! One can get started once commercialization is underway for at least the initial applications.

Steps in Conducting a Benefit-Cost Analysis

Step 1: Define the R&D investment being analyzed.

Consider:

When did investment costs begin?

Who provided funding?

How much?

For a social return analysis, the R&D investment likely predated government involvement and extends through product development.

A public return analysis would consider the investment by the government program being analyzed.

Step 2: Define the beneficiaries and benefits.

Consider:

Who will benefit?

- Customers of technology products
- Society broadly (e.g., via public goods)
- Funding recipients performing R&D (if appropriate to the analysis approach)
- Others

When will they benefit?

How will they benefit?

- Quality improvements
- New Performance attributes
- Cost savings

Are there losses from displacing the defender technology (an offset to benefits, or "negative benefit")?

For a social return analysis, benefits will correspond to the full R&D investment.

A public return analysis will consider only the benefits attributable to the government program being analyzed.

Step 3: Define the alternate investment and outcomes that serve as the counterfactual for measuring additionality.

A social return analysis will focus on comparison of the new technology (often developed with multiple sources of funding) with the pre-existing technology it displaces or possibly an alternative new, competing technology expected to emerge. The additionality effect of the government program helps define the R&D project being analyzed and its counterfactual technology, but benefits included in the analysis are not necessarily 100% attributable to the government program. Focus is on the question:

- What are the gains and losses enabled by the new technology (assuming technological change over the study period)?

A public return analysis explicitly seeks to identify the incremental benefits attributable to the government investment, considering such issues as:

- What level of investment occurred with the public investment *versus without it*? For example, did public funding affect project timing? The probability of success? Whether the project would have been undertaken at all?

A recent ATP benefit-cost study on ATP-Funded DNA Diagnostics technologies provides an illustrative analysis of additionality in a public return system of analysis. (This study focused on comparing ATP-attributable public (non-private) benefits to the ATP investment although some social return analysis was also provided.)[3]

In ATP's Affymetrics-Molecular Dynamics joint venture project (1995-1999), Affymetrix developed a second generation DNA Chip (under their GeneChip Trademark). This new chip was hugely more efficient than the company's first generation chip. However, interviews conducted with the company, its joint venture partner, and industry experts indicated that only 25% of the value of the new chip was attributable to ATP funding. It was believed that the company was doing 75% of the development that was commercialized to date on its own. (ATP funding was applied to a broader spectrum of manufacturing, software, and other R&D tasks that have not yet been commercialized although they may be in the future.) As a result, the study attributed only 25% of the productivity benefit (reduced labor, microarrays, and consumables) of the new chip to ATP.

Affymetrix's partner, Molecular Dynamics, developed a high-throughput DNA sequencer as a result of its ATP funding. It enabled sequencing of large volumes of data about twice as fast as the next best technology at the time and was purchased by the major laboratories engaged in the Human Genome Project. Just one and a half years later, a competitor developed an even faster DNA sequencer. Although, the ATP-funded machine is still being marketed (and the technology was acquired by GE Medical Systems), the benefit-cost study attributed just the one and a half year acceleration of the benefit of rapid sequencing (avoided labor and consumables cost and reduced equipment cost).

[3] See O'Connor, Rose, Gallaher, Sevinsky, and Wood, *Economic Impact of ATP's Contributions to DNA Diagnostics Technologies* (Gaithersburg, MD: National Institute of Standards and Technology, January 2007.

Step 4: Identify benefit and cost cash flows (usually annually).

Once benefits have been identified and attribution issues addressed, benefits and costs are converted into annual cash-flow benefits. As appropriate to the social return or public return analysis approach being used, benefit cash flows will consider:

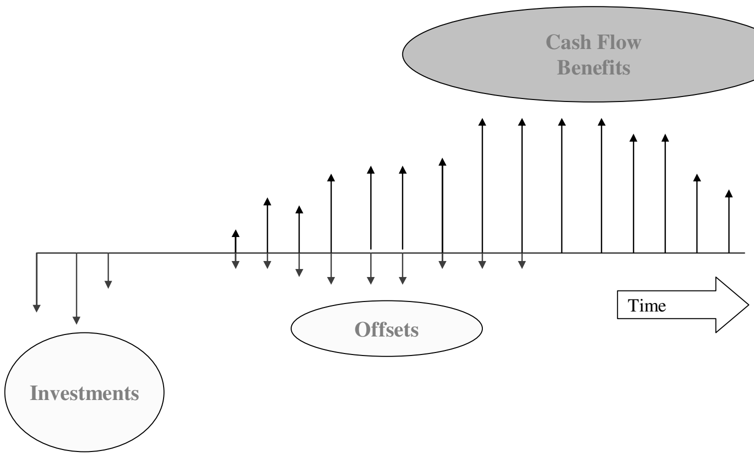
- When did/will benefits begin?
- When did/will benefits end?
- When did/will a new technology displace the technology being studied?

Investment cost cash flows will consider:

- *For a social return analysis,* technology investment costs (from all sources) from R&D inception through product development
- *For a public return analysis,* public funding from the agency/program under study

For a public return analysis, the resulting cash flows tend to follow a time pattern something like shown in the diagram below. Public investment costs occur at the beginning of the project, as negative cash flows. Following a gap during which additional R&D is underway, benefits begin from initial applications and increase over time, as positive cash flows. Benefits are accompanied by losses in profits to competitors with older technologies (offsets to technology benefits). After some period, benefits from the new technology diminish or become too uncertain to be quantified.

Cash Flows for Project



Step 5: State cash flow amounts consistently in constant (real) or nominal monetary value (e.g. dollars/euros) in order to remove effects of inflation over the period benefits accrue.

Expressing future cash flows in terms of monetary value estimates at the time the study is done provides an easy way to generate constant dollar estimates and avoids guesswork about future inflation/deflation.

Energy-based cash flows and others that move differently from base inflation require separate adjustment based on official estimates of future prices of these goods.

Step 6: Select an appropriate discount rate to adjust for the opportunity cost of money.

Cash flows received sooner have more opportunity to be reinvested and grow than those earned later.

Discount rate consistency will be important for meaningful interpretation of individual study results and comparing results of different investments. Because a high discount rate reduces the value assigned to benefits further out in time, public policy sometimes assigns a low discount rate to projects such as R&D that address long-run goals.

ATP uses a 7% real discount rate, in accordance with U.S. OMB Circular A-94 mandate for benefit-cost analyses.[4]

Step 7: Discount all cash flows to a common point in time.

Generally cash flows are discounted back to the time the project started, using the net present value (NPV) formula for a cash flow in future time t; for example,

$B_{NPV\,t} = B_t/(1+d)^t$ where B_t = benefits in future year t and d = the discount rate

This formula is applied to total cash flows in each year; i.e., t = 1 for investment costs the first year of the project (as a negative); t=2 for second year investment costs (as a negative); and benefits in each year (as a positive) for as many years as benefits (net of offsets) are significant and can reasonably be measured.

[4] Office of Management and Budget (OMB), 1992. *Office of Management and Budget Circular A-94.* Guidelines and discount rates for benefit-cost analysis of federal programs, available online at http://www.whitehouse.gov/omb/circulars/a094/a094.pdf.

Step 8: Compute the metrics (for social return analysis, public return analysis, or both).

Combine time-adjusted cash flows to compute:

$$\text{Net Benefits}_{NPV} = \Sigma\text{Benefits}_{NPV} - \Sigma\text{Costs}_{NPV}$$

$$\text{Benefit-to-cost ratio}_{NPV} = \Sigma\text{Benefits}_{NPV} / \Sigma\text{Costs}_{NPV}$$

Compute internal rate of return, the iterative solution for a rate at which the PV of investment cost cash flows equals the PV of benefit cash flows.

Calculate desired performance metrics for different components of desired types of analysis; e.g., social return and its private return and spillover return components, and public return.

In practice, Microsoft Excel's NPV and IRR functions are frequently used and are reliable; however, it is important to test these functions on a simple example performed manually and with Excel. Excel's assumptions in processing cash flow inputs might be a little different from what you anticipate.

Step 9: Assess risks and uncertainties.

Prospective or projected costs and benefits from R&D likely entail considerable estimation error. Establish a probability distribution around cash flow estimates about which there is significant uncertainty—particularly projections of future benefits. Test the sensitivity of study results to estimates involving considerable uncertainty and consider whether it is necessary or useful to report final metrics as an estimate range.

Step 10: Consider potentially important benefits that do not seem to be measurable but can be discussed qualitatively.

Consistent with its mission, ATP projects generate considerable health, safety, environmental benefits to society broadly—beyond direct technology customers or direct users. These benefits sometimes can be discussed somewhat quantitatively, but are often not reflected in the benefit-cost metrics.

Computed metrics generally focus on monetary impacts and generally those monetary impacts that are relatively certain. Metrics encompassing prospective analysis reflect conservative estimates of market penetration and market adoption of new technologies based on considerable market analysis and interview with independent technology experts. Longer-term/less certain benefits are discussed qualitatively, as are broader public goods, such as reduction in fossil fuel usage generally and health benefits.

For example, in ATP's DNA Diagnostics study, the DNA sequencer generated both the monetary impacts described above and several additional impacts that were discussed qualitatively. Evidence was strong that high throughput DNA sequencer greatly accelerated the completion of the Human Genome Project and furthermore that ATP funding of DNA diagnostics projects at a critical time stimulated private investment in this area and helped spawn new companies. These benefits were discussed, and even featured because they directly address ATP's mission, but they were not included in the metrics computed.

Benefit-Cost Analysis in Use: ATP's Studies To Date

Are these studies really being produced? How are they being used?

ATP has published 14 benefit-cost studies, covering 32 ATP projects, to date. All were done by independent contractors. This chart summarizes the studies.

Table 1. ATP's Benefit-Cost Studies To Date

Short Title (# of projects)	**Pub Number**	**Contractor**	**Pub Date**
Green Technologies cluster (**2**)	GCR 06-897	Delta Research	2007
DNA Diagnostics cluster (**2**)	GCR 06-898	RTI International	2007
Photonics cluster (**2**)	GCR 05-879	Delta Research	2005
Composites cluster (**2**)	GCR 04-863	Delta Research	2004
2mm project—retrospective (1)	GCR 03-856	MIT	2004
HDTV joint venture (1)	GCR 03-859	RTI International	2004
A-Si Detectors for digital mammography (1)	GCR 03-844	Delta Research	2003
Component-based software (**8**)	GCR 02-834	RTI International	2002
Closed-cycle refrigeration (1)	GCR 01-819	Delta Research	2001
Digital data storage (**2**)	GCR 00-790	RFF	2000
Flow-control machining in auto industry (1)	NISTIR 6373	NIST-Building & Fire Research	1999
Tissue engineering (**7**)	GCR 97-737	RTI International	1998
2mm—Early assessment (1)	GCR 97-709	CONSAD	1997
Printed wiring board (1)	GCR 97-722	Albert N. Link	1997

Ranging in cost from about $25,000 for the first studies to $250,000 (at the time undertaken), the earliest studies were largely efforts to explore evaluation approaches. They had limited empirical basis. More recent (and more expensive studies) were far more in-depth and empirically based. The complete studies are available on ATP's website for the spectrum of users of ATP information and evaluation practitioners.[5]

Key results are used to document ATP impacts in program reviews for policy and budget makers in the U.S. Congress and Executive Branch and in separate publications featuring results from the spectrum of ATP evaluation efforts.

ATP's studies are part of a much longer NIST history with benefit-cost analysis. NIST Headquarters' Program Office has produced benefit-cost studies of at least 30 laboratory programs since the 1970s, and NIST's Building and Fire Research Laboratory has conducted many benefit-cost studies for its own laboratory programs and for other U.S. agencies outside of NIST.[6]

Extension: Cluster Analysis

With the assistance of its contractors, ATP has extended benefit-cost analysis to a cluster of related projects in a single study. The multi-project studies indicated in the table above can be considered such "cluster studies".

Each of these cluster studies compares the benefits from a small group of related projects, for which benefits have been analyzed in depth, to the investment costs for a broader group of similarly related projects. The resulting metrics provide minimum estimates of return for the broader group.

This approach extends benefit-cost analysis from a single project to a broader part of a program's portfolio. To the extent that a few projects–at the entire portfolio level or in a particular topic area—generate very large benefits, they may justify the investment in the entire area or portfolio. Not all R&D projects will be successful; and some will take a long time to mature even if they ultimately generate significant benefits. The cluster approach takes advantage of the projects that generate significant benefits relatively early to provide a minimum estimate of return for its broader group.

5 All of these studies are available in entirety on ATP's website, www.atp.nist.gov, more specifically: http://www.atp.nist.gov/eao/eao_pubs.htm.

6 See NIST's website http://www.nist.gov/director/planning/impact_assessment.htm

Advantages of Cluster Analysis

The cluster analysis approach has considerable advantages. Most importantly, it is an affordable and practical way to estimate the impact of a portion of a program's portfolio that is of interest. In-depth analysis of a few projects known or believed to be successful can be compared to the costs of the entire member group to enable conclusions about the return from the larger group.

In addition, the cluster analysis approach overcomes comparability issues of studies done at different times by different contractors. They are generally performed by a single contractor or team. They generate a uniform set of metrics computed on a consistent basis.

ATP has performed cluster studies for several of its focused program portfolios, including Component-based Software, Composites, Tissue Engineering, and DNA Diagnostics. (ATP designated portions of its funding for such programs in the mid 1990s.) It has also applied the approach to thematic areas, including Green Technologies and Photonics. (See Table 1 and Note [5].)

The next paper, by Dr. Thomas Pelsoci, presents a case example of benefit-cost analysis from his Photonics cluster study.

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ATP website www.atp.nist.gov, more specifically: http://www.atp.nist.gov/eao/eao_pubs.htm. *Note that ATP is being discontinued. TIP (Technology Innovation Program) will take its place and the website may change accordingly.*

NIST's website http://www.nist.gov/director/planning/impact_assessment.htm.

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Benefit-Cost Analysis: Estimating Economic & Other Benefits from Public Investments in Advanced Technologies

This brief paper provides an example of benefit-cost analysis and concludes with a discussion of how analytical results can be utilized.

Benefit-cost analysis is an empirical methodology for the valuation of technology options developed with public funding. It documents and monetizes economic benefits that have been realized or are expected to result from public investments in high-risk technologies. Beyond economic benefits - amenable to monetized expression – the analysis can also be used to characterize other important benefits that can be more meaningfully captured in a qualitative presentation.

To be of practical use, analysis should be clear, transparent, and credible. Hence, it must be grounded in an essential understanding of the new technology and the prior state of the art. In addition, it must reflect a sufficient understanding of the industries and markets in which the innovation will find commercial application. When assumptions are required, they should be conservative assumptions.

- In line with the requirements of clarity and transparency, benefit analysis must provide a discussion of the technology under investigation. What is the innovation, how does it work, and how do its performance parameters compare to the prior state of the art and to alternative technology options?

- Next, the analysis must identify existing or near-term commercial applications in one or more industries and demonstrate sufficient understanding of industry and market dynamics as to the need for the innovation and the scope of market opportunities. In the case of prospective analysis of benefits, under what market conditions will the innovation be commercialized? Will pricing constraints be severe or can one reasonably expect to price new products and new processes -utilizing the innovation - on the basis of customer value?

- Finally, public benefits of the innovation - to end users and society at large - are identified. For public benefits that can be meaningfully quantified, cash flow estimates are derived for one or more industry applications. Estimated cash flow time series are used to compute metrics, including the net present value of public investment (NPV), the ratio of benefits to public investment (B : C), and internal rate of return on the public investment (IRR).

Case Study: X-Ray Optics for Refinery Process Control

This section summarizes the results of a benefit cost case study conducted for the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST). NIST is an agency of the U.S. Department of Commerce.

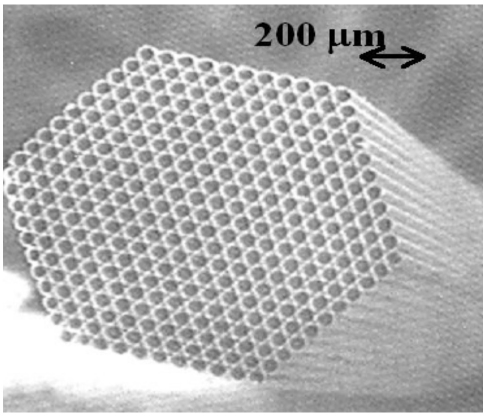
What Was the Innovation?

Accurate information about materials composition and structure can be obtained through X-ray spectroscopy, which measures absorbed or emitted electromagnetic radiation from material samples. X-ray fluorescence (XRF) is one form of X-ray spectroscopy and can be used to accurately detect and measure trace amounts of chemicals. A more wide-spread industrial utilization of XRF techniques would, however, require finding a way to effectively focus X-rays, a form of ionizing radiation.

While the underlying principles for special capillary optics - needed to focus X-rays - were discovered in the 1960s, significant technological uncertainties remained before X-ray optics could be effectively used to increase XRF measurement accuracy and speed in industrial applications – such as the detection and measurement of process impurities.

In 1992 the ATP funded a technology development project to address the remaining technical challenges of focusing X-rays, including the

- Evaluation of alternative capillary materials for X-ray transmission efficiency.
- Controlling radiation damage and heating effects to enhance capillary reliability.
- Developing engineering design methods for working through a large number of computationally challenging design options, including lens geometries, capillary surface roughness, surface waviness, tapered capillaries, and fiber bending.
- Fabrication of high purity, ultra thin, hollow glass tubes with variable cross sections. Developing alignment technologies for assembling hundreds of glass tubes into closely packed capillary arrays, subject to exacting quality standards.



In 1996, the ATP-funded project was successfully completed and resulted in commercially viable optical components for XRF industrial process sensors or "sensor engines" to detect trace level contaminants in petroleum refining and petroleum distribution

Application to Address Industrial Needs?

In 2001, the U.S. Environmental Protection Agency adopted rules requiring drastic reductions in the sulfur content of highway grade diesel fuel to ultra low levels, from 500 ppm (parts per million) to 15 ppm. It was recognized that the petroleum refining and distribution industry would be significantly challenged to achieve 15 ppm ultra-low sulfur diesel (ULSD) levels and that innovative new technologies - that provide orders of magnitude greater accuracy and near real-time measurement of trace amounts of sulfur – would be needed.[1]

> Based on technical advances from the ATP funded project, commercially viable XRF "sensor engines" became available to respond to regulatory requirements and detect trace amounts of sulphur in petroleum refining and refined product distribution.

"XRF sensor engines can provide closed-loop process controls so that refiners can quickly detect 'out-of-spec' diesel products, take corrective action, and avoid un-necessary costs".[2] Significant efficiencies will be realized in

[1] National Petroleum Council, 2000

[2] Beumer and Radley, 2004

- Feedstock Blending: Crude supplies vary significantly in sulfur content. Real-time measurement facilitates the optimal blending of crude oil arriving at distillation columns, reduces process excursions and downtime, and leads to energy savings.

- Hydro-treatment of refinery flows: Real-time measurement of sulfur content prevents "over-treating" or extracting too much sulfur and reduces yield losses.

XRF sensor engines will also result in significant pipeline efficiencies.

- The various grades of motor gasoline, diesel, and other refined products are routinely transported in the same physical pipeline as sequential batches. Batches of petroleum products are pumped through the system and, where adjacent batches come into contact, some mixing occurs between different products. Different refined products that mix at the interfaces (transmix) are generally "off specs" and are downgraded or reprocessed, at additional cost.

- According to the American Petroleum Institute (API), maintaining pipeline product integrity and minimizing costly transmix downgrades is much more difficult when transporting 15 ppm ULSD fuel. API projects that interface mixing of fuel batches and sulfur contamination from other fuels will result in up to 17 percent of ULSD fuels being downgraded and requiring costly reprocessing.[3]

Using XRF sensor engines, developed on the basis of ATP funded technology advances, leads to a reduction in downgraded pipeline products and diesel fuels and the avoidance of associated costs.

Estimating Cash Flows and Financial Metrics

XRF sensor engines will generate various benefits for industry and society at large. They will facilitate industry regulatory compliance, improve refinery quality control, reduce refinery yield losses, reduce highway diesel emissions and enhance public health outcomes.

As a subset of the above benefits, improved refinery and pipeline efficiencies are monetized as cash flows estimates - for a basecase and a more aggressive "step-out" scenario - on the basis of

- Sale of XRF sensor engines to refiners and to pipelines over a ten year study period

- Annual energy savings per XRF sensor engine – from enhanced efficiencies - and

- Projected cost of crude oil feedstock

[3] Peckhan, 2000

Cash flow estimates, over the 2004 to 2014 period, were used to project benefit to cost ratios from $75 to $94 per every dollar of public investment, internal rates of return from 49 to 53 percent, and net present values of the ATP investment from $184 to $224 million.

Higher Level Analysis

Single project analysis of technology investments can generate credible results and lead to interesting insights. However, when the issue at hand is the performance of a cluster of related technologies or the performance of a technology investment program, can benefit- cost analysis be used for higher-level analysis? As a related issue, can benefit-cost analysis avoid the impression of cherry picking the more successful projects?

Cluster studies, focusing on a group of related technologies, are one construct for driving the analysis to a higher level. Several detailed case studies are conducted and their cash flow benefits are compared to the entire investment in a group of related technologies to derive performance metrics at the cluster level.[4]

Higher-level analysis and avoiding the impression of cherry picking can be achieved when benefit cost analysis is institutionalized as a regular management tool in a technology development agency.

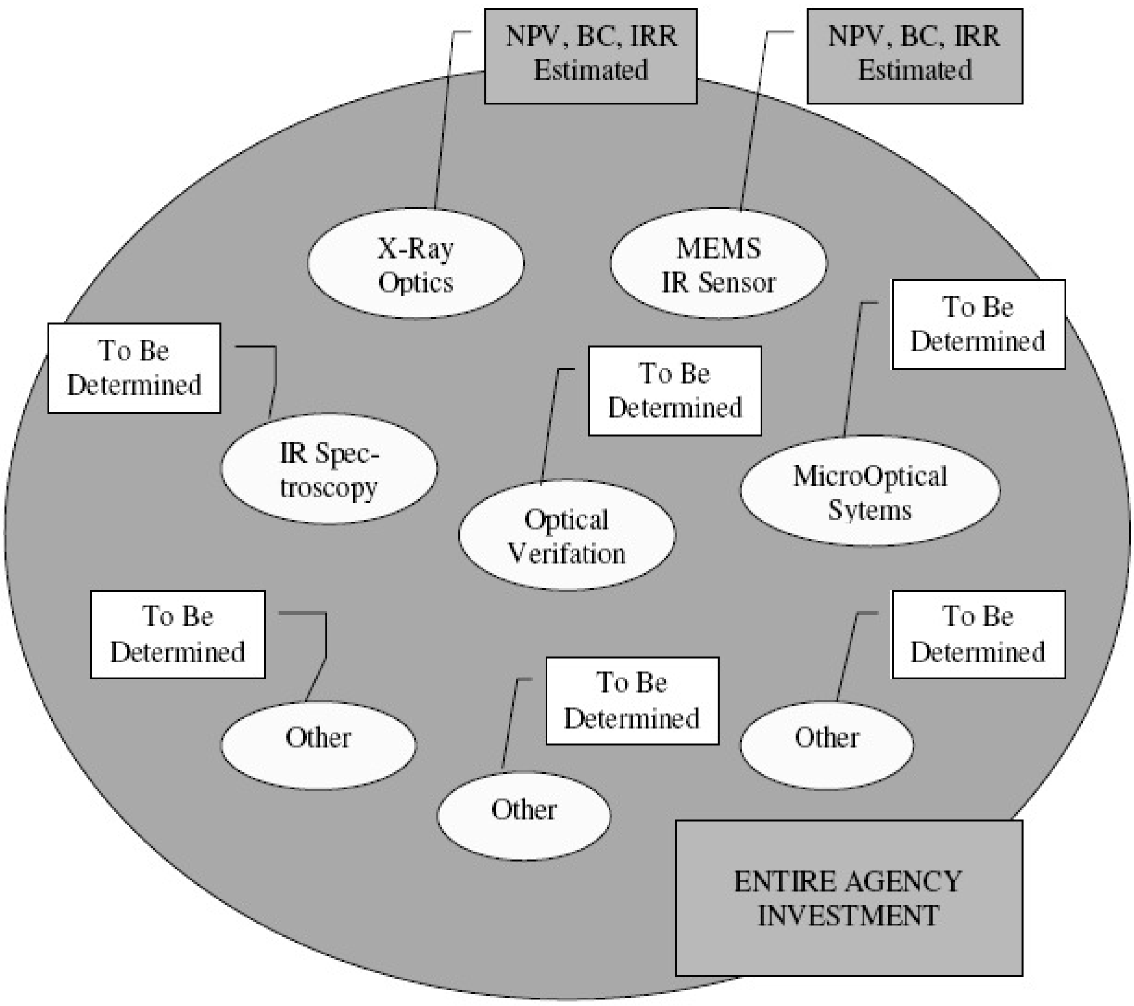
During the first step or pilot phase, a few benefit cost studies are completed. As ATP's investment in X-ray focusing indicates, the results of these pilot studies – in terms of monetized benefits from one or two projects - can be very impressive, even relative to the agency's entire investment portfolio.

However, credibility is built gradually over time as more and more projects are submitted to benefit-cost analysis. Given the time and resource requirements for completing the initial pilot studies, how can institutionalization take place with relative efficiency and effectiveness? One approach would involve using a mix of external and in-house capabilities to conduct this work, over time. This would entail a period of training and in-house skills development as well as continuing use of some external resources to provide elements of objectivity and independence.

[4] See Pelsoci, 2005. Photonics Technologies – Economic Analysis of a Cluster of ATP-funded Projects

When benefit-cost analysis is institutionalized in this manner, a sequence of projects can be evaluated over time using a consistent methodology and, under certain conditions, results from this sequence of projects might be combined. Figure 1 provides a visual display for how this process could work. While there are too many project investments to evaluate all investments, over time an institutionalized process would generate an ever increasing number of data points that could paint a compelling story of the technology agency's effectiveness in terms of enhanced industrial competitiveness and greater benefits to society-at-large.

FIGURE 1: SCHEMATIC REPRESENTATION OF SEQUENCE OF BENEFIT COST STUDIES OVER TIME



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Tracing Innovation

This paper discusses the what, why, and how of tracing innovation, using the methods of historical tracing, citation analysis, and network analysis. It discusses advanced techniques in citation analysis that are helpful for tracing innovation and identifying emerging innovations. It also illustrates tracing innovation with an example from the U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE) Program. The illustrative study traces connections of knowledge outputs from EERE's research in vehicle energy storage to battery and ultracapacitor technologies for hybrid and electric vehicles. Finally, this paper provides additional brief examples of the use of advanced patent citation analysis techniques to trace emerging innovations.

What is Tracing Innovation?

"Tracing innovation" generally it means identifying the paths linking research with outcomes. It can also refer to finding connections between innovation and related further innovative activity. More broadly, the term may also refer to mapping knowledge flows in national innovation systems.

To identify the paths linking research with resulting outcomes, two different approaches may be taken: forward tracing and backward tracing. Forward tracing starts with a research program, and traces forward from this program to downstream outcomes. It attempts to follow all path branches that flow downstream from the research, some of which may lead to innovations and some to dead ends. Thus, it can capture a comprehensive view of how a research program is connected with further developments.

In contrast, backward tracing starts with a selected downstream innovation and traces backward to find out if and how it is linked to the upstream research program of interest. Thus, it provides a narrower view of research outcomes. However, because the backward tracing generally starts with an innovation of recognized importance, it provides evidence that the research program was valuable when it shows linkage from that innovation back to the program's research. Also, focused backward tracing is generally less expensive to perform than forward tracing.

Why Trace Innovation?

One major reason for a research program to sponsor this type of evaluation is to provide evidence to stakeholders that its research is leading to innovation. Another reason for tracing innovation is to illustrate the complex and non-linear processes that typically link research and innovation, which may help to condition public understanding and patience for the length of time taken for applied research to yield results. Applied backwards—from innovation to research—the method can show that a demonstrably valuable innovation is rooted in a specific research program. When applied further downstream, the method can help to identify connections from one innovation to subsequent innovations. Also, when used by an evaluation program that also uses other evaluation methods, tracing innovation can provide an alternative evaluation perspective and an additional line of evidence of research program results.

How to Trace Innovation?

There are three methods that are generally used separately and in combination to trace innovation: historical tracing, bibliometrics, and network analysis.[1]

Historical Tracing Method

The historical tracing method was developed specifically for tracing innovation retrospectively. Traditionally, this method relied chiefly on successive interviews with experts; reviews of documents and existing databases; examination of institutional roles and relationships; and review of a program's objectives, activities, inputs, outputs, outcomes, and impacts. This method is often aided by performing the assessment within the context of a program logic model. Recently, historical tracing is often supported by citation analysis (discussed below).

Examples of the previous use of historical tracing include the U.S. Department of Defense's "Project Hindsight" from the early 1960s, which identified key research outputs that contributed to the realization of 20 major weapons systems. An example from the 1990s is the U.S. National Science Foundation's tracing of linkages from its sponsored research to the development of six major innovations, including the internet, magnetic resonance imaging,

[1] For more on these and other evaluation methods, see Ruegg and Jordan, *Overview of Evaluation Methods for R&D Programs* (Washington, DC: U.S. Department of Energy, Energy Efficiency and Renewable Energy, March 2007), summarized in the introductory paper in this newsletter, and available on-line at http://www1.eere.energy.gov/ba/pba/program_evaluation/evaluation_documents.html.

reaction injection molding, and optical fiber for telecommunications and analog cellular phones.[2]

Bibliometric Methods—Citation Analysis

Citation analysis has become increasingly used in studies to trace innovation. The early focus in this area was on tracking citations of publications and patents, and displaying the results with patent trees to demonstrate the extent to which a patent was being cited, and to show who was citing it. Increasingly, however, the use of simple citation analysis and patent trees alone is recognized as inadequate. Advanced citation analysis techniques are being developed and used to show the relative importance of different patents and patent portfolios.

One problem with simple citation trees is that, while they show knowledge flows, they do not adequately address the fact that patents have vastly uneven value. Most patents are worth very little, while, at the other end of the continuum, a few are extremely valuable. For this reason, citation metrics have been developed to help to isolate the valuable patents. Preferably, these metrics should be normalized to account for differences in patent age, technology, and patent systems. Also, in order to track knowledge flows accurately, it is important that patents be assigned to the organizations that funded them, including an acknowledgement when government organizations have provided funding.

"Hot" Patent and "Next Generation" Patent Analysis

Recently, patent citation analysis techniques have been developed offering ways to identify "hot" patents that are highly influential, as well as "next-generation" patents that are building on these hot patents.[3] This type of bibliometric method provides a way to identify patents whose impact on recent technological developments is particularly strong. Also, groups of next-generation patents can be identified as they cluster around a particular patent, and new patents

[2] Earlier examples of tracing studies include the following: C.W. Sherwin and R.S. Isenson, "Project Hindsight: Defense Department Study of the Utility of Research," *Science,* 156 (1967), pp. 1571-1577; David Roessner, Barry Bozeman, Irwin Feller, C. Hill, and N. Newman, *The Role of NSF's Support of Engineering in Enabling Technological Innovation*, first year final report for the National Science Foundation (Arlington, VA: SRI International, January 1997), available on-line at www.sri.com/policy/csted/reports/sandt/techin/welcome.shtml; and David Roessner, R. Carr, Irwin Feller, M. McGeary, and N. Newman, *The Role of NSF's Support of Engineering in Enabling Technological Innovation: Phase II*, final report to National Science Foundation (Arlington, VA: SRI International, May 1998), available on-line at www.sri.com/policy/csted/reports/sandt/techin2/contents.html

[3] For further details on the Hot Patent and Next Generation Patent techniques, see P. Thomas and A. Breitzman, "A Method for Identifying Hot Patents and Linking them to Government-funded Scientific Research," *Research Evaluation*, Volume 15(2), 2006, 145-152.

can be added to clusters at the time they are granted. This helps to identify new organizations entering a given hot technology area.

Data Mining

Data mining is another bibliometric method that has been used to trace innovation, showing the origin of important ideas and concepts. This method searches large quantities of digitized text to identify instances of keywords. It can be used to identify the origin, emergence and further development of ideas and concepts, and to reveal relationships among research organizations and disciplines. Information visualizations may be usefully added to data mining to assist in interpreting the results.

Network Analysis

One non-bibliometric method that can be used to map knowledge flows among individuals and organizations, and applied to tracing innovation, is network analysis. In contrast to the bibliometric methods, which show how knowledge is disseminated via citing publications and patents, network analysis shows how knowledge is disseminated via communication flows among people and/or organizations. The network identifies paths of interaction among parties in "communities of practice". The shape, size, and density of interactions provide indicators of the strength of such communities and the roles and relationships of entities within a community.

A Tracing Example from the U.S. Department of Energy

A recent example of an innovation-tracing study is one supported by the U.S. Department of Energy (DOE) and conducted by the authors of this paper.[4] The study, which was primarily a backward tracing study with elements of forward tracing, identified and documented linkages from battery and ultracapacitor technologies for hybrid electric (HEV), plug-in hybrid electric (PHEV), and electric vehicles (EV) back to DOE's research programs in energy storage for vehicles from 1976-2007.

Methods used by the study included historical tracing, institutional analysis, and patent citation analysis. The study approach started with expert interviews and formulation of hypothesized linkages in the specified application areas. It then conducted an institutional analysis, document review, and preliminary patent analysis to test the hypothesized linkages, document evidence,

[4] For the full report from which the energy storage tracing example is drawn, see Ruegg and Thomas, *Linkages from DOE's Vehicle Technologies R&D in Advanced Energy Storage to Hybrid Electric, Plug-In Hybrid Electric, and Electric Vehicles* (Washington, DC: U.S. Department of Energy, Energy Efficiency and Renewable Energy, publication in process January 2008); to be available after publication on-line at http://www1.eere.energy.gov/ba/pba/program_evaluation/evaluation_documents.html.

and identify any other linkages. The document review yielded information on licensing and patent infringement. Finally, the study performed a detailed backward-tracing patent citation analysis that identified HEV, PHEV, and EV battery and ultracapacitor patents linked to DOE-funded patents, in comparison to those linked to other organizations—including major Japanese battery suppliers.

The expert interviews pointed to a number of different paths through which DOE has influenced HEV, PHEV, and EV battery and ultracapacitor technologies. One main path was through dissemination of technologies developed by companies funded in part by DOE through an industry consortium, the U.S. Advanced Battery Consortium (USABC). Payment of royalties to DOE by one of the companies provided evidence of downstream use of the nickel metal hydride (Ni-MH) battery technology supported by DOE through USABC. Extensive licensing of this company's Ni-MH technology to all major battery suppliers around the world provided further evidence of widespread dissemination of this DOE-supported battery technology. Charges of patent infringement brought by the same company against major Japanese battery producers, and the terms of the settlement of this lawsuit, provided further evidence of dissemination of the DOE-funded battery technology to foreign battery suppliers.

Additional paths of influence were licensing of DOE National Laboratory technology to battery suppliers; industry adoption of DOE test protocols; and expansion of the knowledge base reflected in papers and presentations. Not just DOE-funded companies, but also scientists and engineers in the National Laboratories have developed energy storage technologies which have been licensed to battery companies for further development and commercialization. The National Laboratories have also developed battery test protocols for hybrid and electric vehicles that have been adopted by the Society of Automotive Engineering as recommended practices for battery testing, and used by the auto industry. And, although less effort was spent on documenting linkages in this area, the establishment of an extensive body of scientific and engineering papers and presentations by DOE-funded scientists and engineers in government laboratories, university, and industry also have provided the foundations for further advances in energy storage technologies.

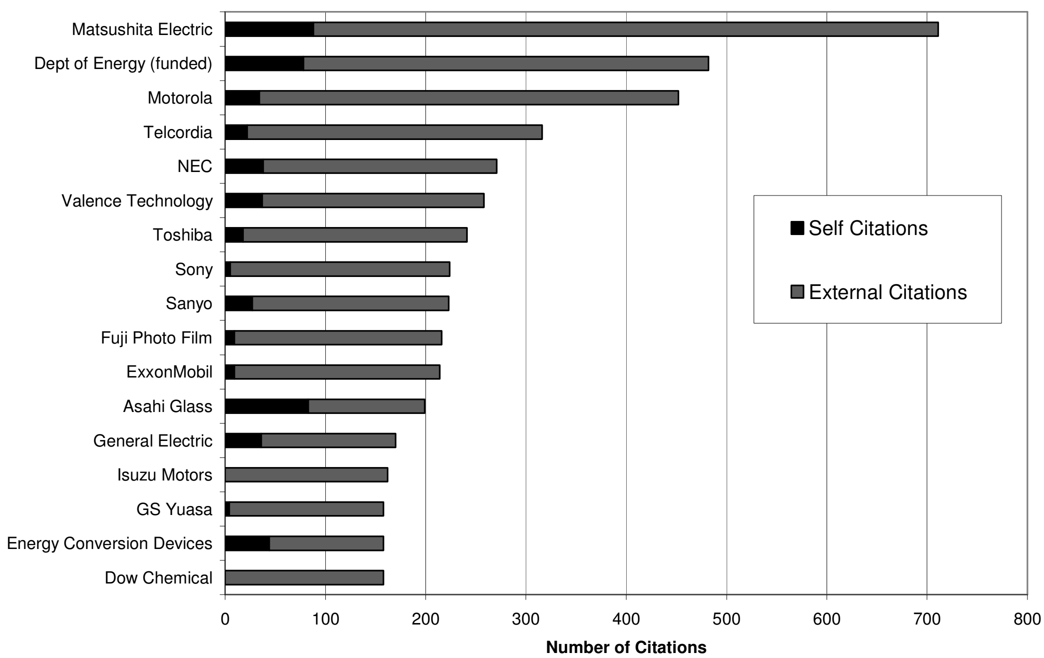
The analysis of institutional roles and relationships established the institutional context for understanding how and why linkages may have developed between DOE-funded energy storage research for vehicles and battery and ultracapacitor technologies for hybrid and electric cars. It identified the principal organizations, programs, and initiatives that have contributed to the development of advanced energy storage technologies for HEVs, PHEV, and EVs with DOE's support.

Many or most of the companies funded through by DOE through the USABC did not note the DOE interest in their patent filings. As a result, in order to carry out the patent citation analysis, it was necessary first to identify the population of U.S. patents linked to DOE-funded research.

This DOE patent set was then linked to downstream HEV/PHEV/EV applications patents. The patents of other leading organizations in battery and ultracapacitor technologies were also linked to the HEV/PHEV/EV patents to provide comparison.

Figure 1 reveals the organizations whose patents have been cited most frequently by HEV/PHEV/EV battery and ultracapacitor patents. This figure reveals that the portfolio of DOE-funded patents is the second most frequently cited, after the portfolio of Matsushita Electric. Further analysis of the pattern of citations also suggested that inventions from the different groups funded by DOE have had a strong influence on each other. The full study report contains many additional comparisons of patenting in this area among leading organizations.

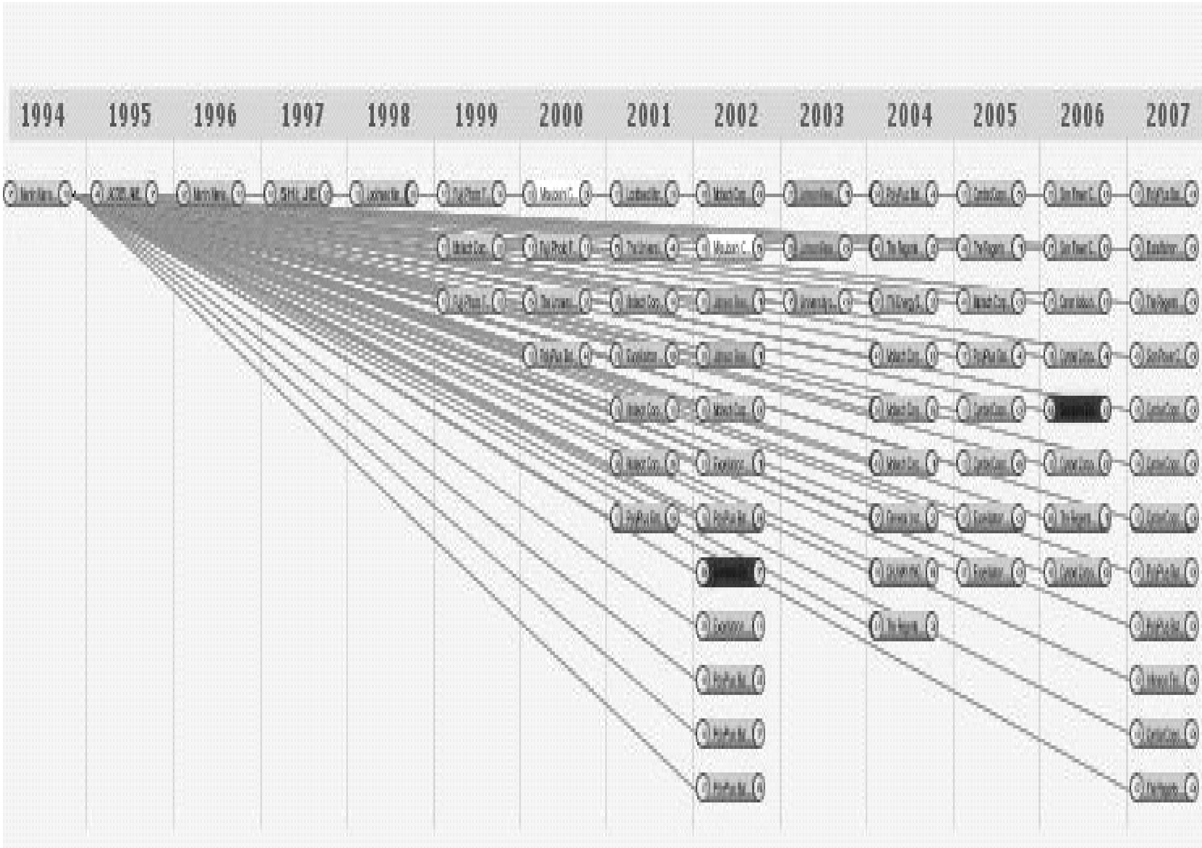
Figure 1. Organizations whose Patents are Cited Most Frequently by HEV/PHEV/EV Battery/Ultracapacitor Patents



At the patent level, the study's analysis revealed specific DOE patents that have been particularly influential, that is, DOE-funded patents that have been cited by the largest number of HEV/PHEV/EV battery/ultracapacitor patents. Patent trees were generated for several of the most influential patents, such as that illustrated in Figure 2 for Lockheed Martin's Patent #5,314,765.

A principal conclusion of the study is that DOE research in energy storage for vehicles has played a significant role in helping to establish the foundation for battery and ultracapacitor technologies for HEVs, PHEVs, and EVs. DOE-funded research was found to be linked to three of the most prominent energy storage technologies for applications in these hybrid and electric vehicles: nickel metal hydride batteries, lithium-ion batteries, and ultracapacitors.

Figure 2. Seventy patents have cited Lockheed Martin's Patent #5,314,765, Issued in 1994, Titled "Protective lithium ion conducting ceramic coating for lithium metal anodes and associate method"



Examples Using "Hot" Patent and "Next Generation" Patent Analysis

This final section of the paper provides a brief overview of hot patents and their use in innovation tracking exercises. As noted earlier in this paper, 'hot' patents are those that receive a large proportion of their citations from patents issued in the most recent time period. These hot patents may be older patents that have been ignored for a long time period before becoming influential. Older patents may become "hot" in cases where a particular technology has become feasible for the first time. For example, a technology may require computer processor speeds that have only recently become possible, or may require materials that were prohibitively expensive in the past. Alternatively, older hot patents may describe technologies that have been combined with other technologies by recent researchers, thus generating new interest in these older technologies. Hot patents may also have been issued relatively recently, such that all citations to them are necessarily from recent patents. These newer hot patents may represent emerging technology areas that are generating strong interest from a variety of organizations and research groups.

Hot patents have been used to demonstrate the impact of government funding on the development of high impact technologies. For example, it was shown that patents that cite scientific papers funded by U.S. government agencies are much more likely to become hot patents than patents that do not have this link to government funded research. The impact of government funding has also been depicted geographically, by linking hot patents across U.S. states and congressional districts to research funded by the U.S. Department of Energy. (Details of these studies can be found in the paper referred to in endnote 3 of this paper.)

Recent patents that cite hot patents are referred to as 'next generation' patents, in that they represent the recent developments building on an underlying, high-impact technology. In a study for the U.S. Department of Commerce Technology Administration, 1790 Analytics LLC clustered these next generation patents in order to identify areas of emerging technology.

The referenced U.S. Technology Administration study produced some interesting findings. One notable finding was that many of the clusters based on U.S. patents were related to information technology, telecommunications, and semiconductors. Meanwhile, European patent clusters had a stronger focus on life sciences such as biotechnology and pharmaceuticals. Examples from both the U.S. and Europe were highlighted in that report. They include technologies as varied as stackable 3-D memory chips; techniques for leukemia detection; invisible barcode technologies; and laminate flooring panels with noise dampening features. In each case, these groups of next generation patents cluster around an older hot patent that has had a strong impact on recent technological developments.

Summary

In this paper, we have provided brief treatments of evaluation methods used to trace from research to innovation and from innovation to further innovation. We have presented highlights of a recent tracing study to illustrate how several of the evaluation methods were used in combination to trace from advances in battery and ultracapacitor technologies for hybrid and electric vehicles back to a government research program—in this case, the U.S. Department of Energy's research program in energy storage for vehicles. We concluded the paper with short additional examples of how advanced patent citation analysis techniques can be used to identify "hot" patents that have been recently heavily cited and "next generation" patents that cluster around these hot patents. We also highlighted how this type of analysis can be used to characterize impact, identify clusters geographically, and compare the technology focus of different clusters.

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Barbara Birke

- Enhancing Quality in Process Management – Experiences of Benchmarking Exercises

Background

The Austrian Agency for Quality Assurance (AQA) provides support to universities in the development of their quality management systems in selected performance areas through an innovative external quality assurance (Quality Audit) procedure[1]. The AQA procedure is based on the principle that the university is responsible for the development of its own internal quality management system. The procedure supports the quality management system of the higher education institution in respect of its own aims in specific performance areas (teaching, research, personnel management, internationality/mobility) and strengthens the self-governance capability of the institution.

Since 2004 the AQA has been conducting a subject-specific comparison of higher education institutions and has identified a growing need for further development of the methodology and content of such comparisons as instruments of quality development and identification of the particular characteristics of higher education institutions.

As a result, the AQA has developed a benchmarking procedure within its Quality Audit procedure. The benchmarking procedure provides support to the universities' quality management systems by comparison and mutual exchange on processes and their effectiveness with the support of an external quality assurance agency and experts. Process improvement focuses on quality and management issues in selected performance areas.

Characteristics and targets of the AQA's benchmarking procedure

The term 'benchmarking' is being used in varying ways and there is a wide range of definitions and typologies of benchmarking procedures[2]. Some terms appear repeatedly, like external and internal benchmarking, competitive and collaborative benchmarking and process-oriented

1 http://www.aqa.ac.at/download.401.qm-procedure-aqa.pdf

2 cp. Commonwealth Higher Education Management Service, Benchmarking in Higher Education: An International review, 1998, http://www.acu.ac.uk/chems/onlinepublications/961780238.pdf; Hämäläinen, Kauko et al., Benchmarking in the Improvement of Higher Education, ENQA Workshop Reports 2, Helsinki, 2002, http://www.enqa.eu/files/benchmarking.pdf; European Benchmarking Initiative (EBI) in Higher Education, Background, definitions and approaches of benchmarking, paper presented at the EBI Symposium, Brussels, 8 November 2007; Engelkemeyer, Susan West, Applying Benchmarking in Higher Education: A Review of Three Case Studies, in: Quality Management Journal, Volume 5, Issue 4 (1998).

and indicator-based benchmarking. They shall not be described in this article but are used as a reference to describe the characteristics of the AQA's benchmarking procedure.

The AQA benchmarking is an external collaborative benchmarking providing comparisons within a larger group of institutions in the same field that are not immediate competitors.

It is a process-based benchmarking looking at processes and their results. The objective of the procedure is process improvement. The indicator-based comparison is an additional means of the AQA's procedure, but has subordinate importance.

Benchmarks are not pre-determined but developed through the process.

A final characteristic refers to the question what 'true benchmarking' is. Benchmarking literature[3] describes 'true benchmarking' as an instrument for quality enhancement by identifying good practices and adapting them in order to continuously improve the institution's performance (Benchmarking in the Improvement…). Consequently to what has been said above, this characteristic applies to the AQA's benchmarking procedure.

Following these characteristics the core targets of the AQA's benchmarking process can be summarised as follows:

1. Process optimisation in selected key processes (teaching, research, personnel management, internationality/mobility),
2. Exchange of experiences and process oriented comparison,
3. Identification of meaningful key indicators for performance comparisons in selected key processes,
4. Incorporation of the findings of the benchmarking process into the university's own quality management.

The procedure

The benchmarking process is carried out within phase 1 of AQA's QM-procedure which provides external expertise and support within a selected performance area. The process comprises four stages and its design is planned within a group of 4 or 5 higher education institutions. Each stage is supported by at least one Workshop.

3 Benchmarking in the Improvement of Higher Education, ENQA Workshop Reports 2, Helsinki, 2002, http://www.enqa.eu/files/benchmarking.pdf

1. **Selection and description of key processes**

   Constitution of the project group, selection of key processes for process optimisation, description and visualisation of key processes

2. **Analyses**

   Process assessment, derivation of examples of good practice, analyses of key processes at individual university

3. **Process Improvement**

   Development and implementation of measures for improvement

4. **Evaluation and Enhancement**

   Evaluation of implemented measures and enhancement, decision on further procedure and transfer

The entire process is supported and co-ordinated by AQA, an external process-promoter and experts in higher education and/or a specific subject field.

The first two stages of the process are dedicated to the actual benchmarking process. In stage one the process group is constituted, the key processes are selected jointly and the targets for process improvement are developed. The project group agrees on the methodology. This stage typically requires one or two Workshops.

The following description and visualisation of the selected key processes build the basis for the analytical phase which typically starts with a Workshop. Key elements and indicators of the selected processes are presented, analysed and compared targeting at the derivation of examples of good practice. Each higher education institution analyses its own processes in reference to the example(s) of good practice and develops strategies for quality and process improvement.

In addition to the actual benchmarking exercise, the AQA's procedure provides assistance to the higher education institutions in the development, implementation and evaluation of the measures for quality and process improvement. Experiences with the implemented measures are documented by the HEIs, and analysed and discussed within the project group and with the experts at the occasion of two Workshops.

Experienced Benefits and Challenges

In 2007, the project 'Enhancing Quality in Research Process Management' was started on the initiative of several European Universities in the field of Life Sciences[4] and with the external support of AQA. The process is currently undertaken by four European universities.

The starting point of the project was the fact that for universities in the area of Life Sciences in most cases there were no other universities with a similar profile within the same country so that there was no possibility to carry out comparisons on national level. In its original design, the project mainly focused on a comparison alongside selected achievement indicators and a continuous process of improvement via mutual exchange.

In the course of the project the procedure has been developed jointly in the project group and adjusted to the universities' needs step-by-step. Whereas the methodology was not subject to substantial changes, the perspective and target have been broadened from an international comparison to the development of strategies for quality and processes improvement.

Currently, the AQA is developing a benchmarking project together with Austrian Fachhoch-schulen which is likely to concentrate on processes in the area of teaching.

The experiences with the two procedures show some characteristics that similarly hold benefits and challenges that have to be dealt with when carrying out a benchmarking procedure. The AQA's experiences largely correspond with those presented at the occasion of the European Symposium on benchmarking initiatives[5]. The most significant will be presented below.

Partnership and commitment

The success of a benchmarking process very much depends on the quality of the partnership as regards trust, mutuality, continuity and commitment.

During a benchmarking process, an exchange of experiences on confidential data and internal information typically takes place. A culture of trust and confidentiality therefore is a vital pre-requisite from the onset of the project and a big challenge for the constitution of the partnership. At the best, the benchmarking process gets started out of an existing project group, e.g. a benchmarking club (like Benchmarking Club Technischer Universitäten (BMC) in Germany[6]) or out of an existing network (eg. European Consortium of Innovative Universities[7] or

[4] ELLS – Euroleague for Life Sciences, www.euroleague-study.org

[5] EBI Symposium, Brussels, 8 November 2007.

[6] http://www.che-concept.de/cms/?getObject=260&getName=Projekt&strAction=show&PK_Projekt=80&getLang=de

[7] http://www.eciu.org/

Euroleague for Life Sciences[8]). In a different – more delicate case – the process is initiated by one or two institutions looking for comparable but not competitive partners. From experiences, in this case the constitution and retention of the project partnership is one of the most crucial issues and requires a preliminary leading time which is often underestimated.

In addition, the successful constitution of the partnership does not necessarily guarantee continuity of the partnership and equal commitment of the partners. Besides the fact that the effort that has to be made is often underestimated, changes in the institutions' priorities or changes in the management may and sometimes do lead to a reduced commitment to the process even when it has already started.

Written commitments and agreements as well as process handbooks provide process support and steadiness. Given the voluntary character of a benchmarking process their use as a matter of fact is limited.

The issue of commitment does not only apply to the partnership but also to internal efforts that have to be made within the process. Even if there is a high commitment by the institution's management, the operational tasks of describing processes, collecting and formatting data etc. are time intensive and often have to be carried out alongside the day-to-day business. As experienced, the scale of analysed processes has to be restricted to a maintainable extent in order to foster also the commitment of the staff.

Self analyses and recognition of individual progress

The self analyses process starts with the description and visualisation of the selected key processes and the collection and preparation of data and background information. The participants to the benchmarking process reported that they had highly benefited from the process from the very beginning of the project. They soon became aware about strengths and weaknesses of processes and the availability and quality of documentation. High achievements gained at the beginning of the project help to strengthen the partners' commitment and motivation despite the fact that the self-documentation phase is regarded as time and resource intensive.

Selection of benchmarking targets and processes

The development of the process targets and the selection of the processes at the beginning of the project turned out to be an analytical and very collaborative task. It proves very soon whether there is a common understanding and interest within the project group or not. The challenge of this process step is to limit the range and number of processes to a realistic extent without

8 www.euroleague-study.org

reducing the benefit for the participating institutions. According to experience, it is favourable to pursue the selection process step-by-step.

In the above-mentioned benchmarking exercise the selection of the key–processes was carried out thoroughly in two steps. In a first instance, the project group agreed on the enhancement of processes in the area of research, with special regard to profiling, personnel management and management of research projects. Based on written self documentations and the exchange of experiences at the following Workshop the project group decided unanimously to focus on quality and management issues in the recruitment, promotion and retention of academic staff. The step-by-step procedure supported the selection of a specific but common topic which was of high relevance for all participating institutions.

Support by an external agency and experts

The benchmarking process does not necessarily have to be supported by an external institution but obviously is of some value for several reasons. Results of a European study[9] show that moderated groups and processes are more likely to achieve the project goals.

The separation of tasks (co-ordination at the one hand and self-analysis and improvement on the other hand) and the integration of a moderating third party positively influence the success of the process. In a moderated process partners have the same workload and the tasks are equally distributed. The exchange of – above all –written data does not take place from the partner institutions to a lead partner but from all partner institutions to a third party. Thus, the equivalence as regards quality and quantity of the data and the mutuality can be fostered.

In the AQA's benchmarking procedure support is provided by a co-ordinator of AQA and at least two experts. The (external) process-promoter ensures that the processes go according to the procedural plan agreed within the project group and he/she prepares and moderates the process and the Workshops. Experts provide expertise in higher education management and/or a specific subject field (e.g. personnel management of academic staff, Life Sciences) and bring in knowledge on good practices on a transnational level.

Language issues

For benchmarking processes carried out on an international level the issue of languages might become significant. While meetings and Workshops take place in a common project language, it might be challenging and an extra effort to provide written information in a foreign language.

9 Benchmarking in Higher Education – Approaches and methodologies: The findings of the EBI project, Presentation at the EBI Symposium, Brussels, 8 November 2007.

So far, this has not led to major obstacles, but we have experienced some additional effort for the higher education institutions that they obviously had not been aware of before.

Process follow-up

It is noticeable that the bigger part of the benchmarking processes is not followed up as regards the implementation and evaluation of derived measures for improvement[10]. Incidentally, the same applies for the identification of total process costs.

In the AQA's benchmarking procedure the implementation, evaluation and enhancement of measures for quality and process improvement build an important part of the process. Naturally, within a two-years project life time only short term impacts and first experiences can be assessed. A recurring follow-up could be envisaged.

Final remark

The AQA's benchmarking procedure has been implemented within two projects. The co-operation with the benchmarking partners within this new procedure was and is a valuable exercise and enables to continuously improve the procedure.

Also, first experiences with the AQA's benchmarking procedure correspond with those presented at the occasion of a European Symposium on benchmarking initiatives[11]. The AQA would appreciate to continue the dialogue on current benchmarking practices and challenges as well as on the enhancement of benchmarking procedures with institutions involved in similar processes.

10 EBI Symposium, Brussels, 8 November 2007

11 EBI Symposium, Brussels, 8 November 2007.

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Martin Weber and Gareth Roberts

Evaluating the EU Research and Technological Development (RTD) framework programmes - could the Commission's approach be improved?

Some background information on the European Court of Auditors' audit of the Commission's evaluation system for the Research and Technological Development (RTD) framework programmes

INTRODUCTION

In December 2007, the European Court of Auditors published a report on the European Commission's system for evaluating the EU RTD framework programmes detailing the conclusions and recommendations of an audit carried out on this subject during 2005 and 2006. Whilst perhaps better known for its audits of the financial aspects of the European Union's budget, the Court also carries out such **performance audits** to verify whether the EU programmes and policies are efficient and effective and whether they are managed economically.

Box 1: The **European Court of Auditors (ECA)** is the European Union's external auditor. It promotes accountability and transparency and assists the European Parliament and the Council in overseeing the implementation of the EU budget. It examines whether financial operations have been properly recorded and disclosed and whether they were executed legally and in accordance with the Regulations so as to ensure economy, efficiency and effectiveness.

Performance audit and evaluation - is there a difference?

Performance audits and evaluations have many things in common. Both activities are evidence-based inquiries and also share similar objectives including the assessment of the efficiency and effectiveness of projects, programmes or policies. They may also aim to verify the relevance and utility of programmes and policies (although there is some debate as to whether this should be the role of a public audit body). Furthermore, similar methods for collecting and analysing data are used. Therefore, auditors and evaluators require similar knowledge, skills and experiences to carry out their work. Last but not least, performance audits and evaluations are also addressed to similar audiences.

Hence, at first sight, the proposition to audit evaluations, or evaluation systems for that matter, might appear to be an odd one. However, there is one very important difference between audit and evaluation. Whilst evaluation is the responsibility of the management implementing a policy or a spending programme (part of the "internal control function" of a ministry, a funding agency or, in the European context, the Commission), auditors, on the other hand, have a mandate and duty to be entirely independent.

This short paper will provide some background about the subject of the audit and the main elements of the audit fieldwork and summarise the audit's conclusions and recommendations.

The EU RTD framework programmes and their evaluation

The role of the EU in supporting RTD is provided for in the EU Treaty, which also lays down the objectives of strengthening "*… the scientific and technological bases of Community industry…*" and encouraging it "*… to become more competitive at [the] international level …*".

Through its multi-annual **RTD framework programmes (FPs)**, the EU provides funding to researchers within its Member States, associated countries and international organisations. In the current FP7 (2007 – 2013), annual funding averages 7,2 billion Euro (see Figure 1). The overall share of the FPs in total public RTD funding within the European Union and its Member States ranges between 4 % and 5 %.

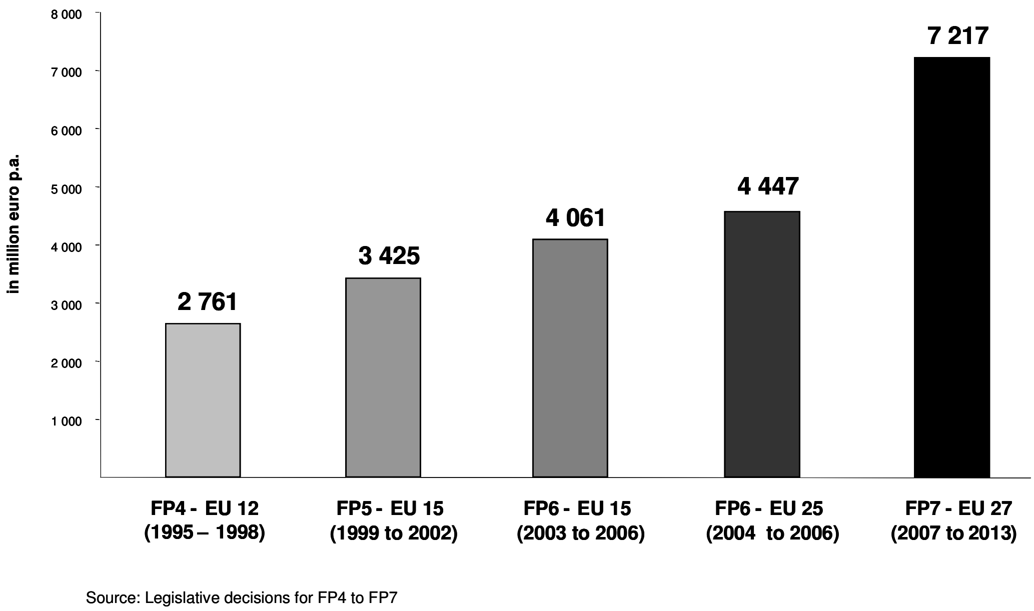


Figure 1: Average annual Community financial participation - FP4 to FP7 (EC)

The **FPs differ from many national research programmes** in that they cover both basic and applied research, with the participation of industry and public research organisations. They are made up of specific programmes (and sub-programmes) dealing with broad scientific fields. These programmes typically consist of a number of domains that concentrate on more specific scientific areas. These domains are then implemented through projects (called "indirect actions") following calls for proposals. In this way, hundreds of individual projects are funded per domain. The FPs are implemented jointly by six Directorates-General (DGs), the so-called "research DGs".

In accordance with the EU Financial Regulation, the Commission is responsible for programme implementation and the assessment of programme results. Within the Commission, evaluation is decentralised to the DGs, with the Commission's central departments (in particular DG Budget and the Secretariat-General) providing support and coordination.

The Commission has had a system for **monitoring and evaluating** its FPs in place since the 1980s. Starting with FP4 in the mid-1990s, the monitoring and evaluation system consisted of a number of partly linked activities, including annual monitoring (mainly of programme implementation) and five-year assessments (5YAs) of FP activities (and, as from FP6, additional assessments of specific issues). Both activities had to be carried out with the assistance of external experts.

THE COURT'S AUDIT OF THE FP EVALUATION

The Court's audit of the evaluation system for the FPs was an attempt to provide a **balanced and independent assessment** of the Commission's work in the field of research evaluation. Its findings, conclusions and recommendations, together with the Commission's official replies, were adopted by the Court in November 2007 and published as Special Report N° 9/2007 one month later[1].

The idea of carrying out this audit dated back to 2004. In a **previous report, on the Commission's management of FP5**[2], the Court had found significant weaknesses in the Commission's internal reporting to management. In particular, the audit found that there was no systematic reporting to the Commission's senior management, including the Commissioners or the Directors-General of the various "research DGs", about the scientific results obtained, the

[1] European Court of Auditors, Special Report N° 9/2007 "Evaluating the EU Research and Technological Development (RTD) framework programmes - could the Commission's approach be improved?", together with the Commission's replies, 20.12.2007 (http://eca.europa.eu/portal/pls/portal/docs/1/651520.PDF; publication in Official Journal forthcoming).

[2] European Court of Auditors, Special Report N° 1/2004 on the management of indirect RTD actions under the fifth framework programme (FP5) for research and technological development (1998 to 2002), together with the Commission's replies (2004/C 99/01), 23.04.2004.

impact of research projects funded by the European Union and the extent to which objectives were reached.

In its official reply to this report, which was submitted to the European Parliament and the Council, the Commission pointed to its evaluations of the FPs by external experts. Moreover, in its reply, the Commission referred to improvements that it intended to introduce for its evaluation system for FP6 (which was still being developed at the time) and, in particular, to the forthcoming 5YA in 2004[3]. This was the starting point for a closer look at the way in which the Commission assessed the results of its funding activities.

Defining the scope of the audit

Before embarking on a full-scale performance audit, the Court carried out a **preliminary study** in 2005. In addition to enabling the auditors to obtain a sufficient understanding of the field, the aim of such preliminary studies is to conclude on the feasibility of an audit, to define its scope and to propose audit questions that can be used as guidance in the subsequent stages.

A final decision to carry out the audit was taken by the ECA in September 2005. In the **detailed planning memorandum** for this performance audit, it was specified that its main objective was to determine whether the Commission had an adequate approach to assessing the results of the FPs.

The scope of the investigation was understood to include not only a verification of compliance with the legal requirements specified by the legislator, but also (and maybe more importantly) a check as to whether the expectations of the main stakeholders had been met.

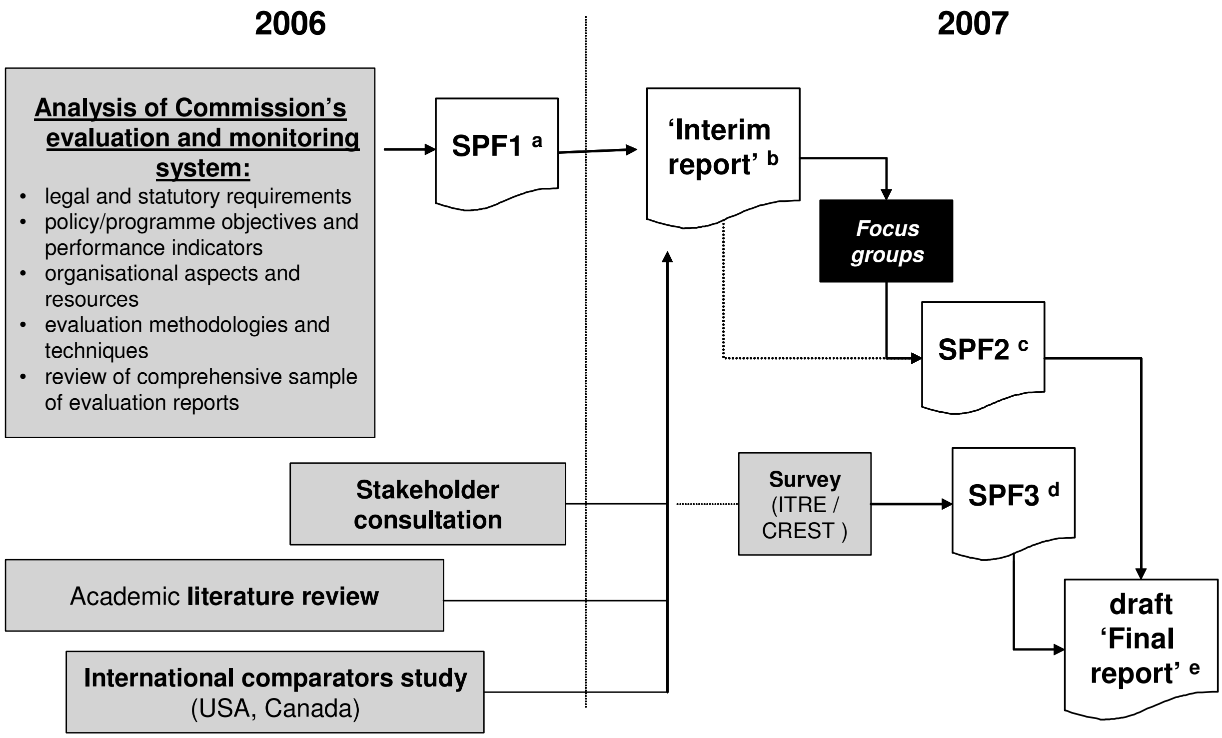
In December 2005, the Court also agreed to the EFTA Board of Auditors' request to participate in this audit. EFTA countries are associated with the FPs and thus contribute towards their budgets.

The main features of the Commission's evaluation system had remained unchanged since the mid-1990s. Therefore, it was decided that the audit should cover the relevant arrangements for evaluations under the last three programming periods, i.e. FP4 (1995 – 1998), FP5 (1999 – 2002) and FP6 (2003 – 2006). However, it was established that it should also provide an outlook on the current FP7 (2007 - 2013) and should, within the framework defined by the legislator in the programme decisions, **make recommendations** on how to improve matters.

3 European Commission, "Five-year Assessment of the European Union Research Framework Programmes, 1999-2003"; Report of the Independent Expert Panel chaired by Erkki Ormala (15 December 2004).

The audit fieldwork

The audit fieldwork, carried out by a team of **four auditors**, started in October 2005 and was finalised approximately one year later. Nearly all the team members had had previous experience with performance audits or evaluations in the research area. The various stages of the audit are depicted in Figure 2.



Note: ***SPF*** *– Statement of Preliminary Findings*

a) *SPF1: Covering mostly systems description,* dispatched on 27 July 2006; Commission reply dated 26 October 2006; follow-up 30 November 2006, reply follow-up 5 February 2007
b) *'Interim' report: Used as basis for focus group discussions,* dispatched on 9 February 2007 to 'Focus group' participants
c) *SPF2: Complete analysis covering all main aspects of the audit,* dispatched on 15 March 2007; Commission reply dated 15 May 2007
d) *SPF3: Results of surveys of CREST and ITRE committees,* dispatched on 11 May 2007 (no response requested, only transmission of factual survey results)
e) *draft 'Final report':* first reading on 1 June 2007, adopted by Court on 5 July 2007; contradictory with Commission on 9, 22 and 29 October 2007; final adoption (together with Commission replies) by Court on 22 November 2007

Figure 2: Performance audit of the Commission's evaluation system for the FPs

The audit started out with a detailed **review of the legal and statutory requirements** applicable to FP evaluations (such as the legal basis for the FPs, the EU Financial Regulation, the Commission evaluation standards and guidelines and examples of international good practice in research evaluation). Subsequently, the auditors analysed the **objectives and performance criteria** specified for the FPs and their constituent programmes (both at the policy-level defined in the legislative acts and at the operational level of the Commission's work programme) and the management information available within each of the "research DGs".

Finally, the audit looked at the **organisation of evaluation and monitoring activities** within the Commission and scrutinised a comprehensive sample of more than 80 **monitoring and evaluation reports** produced during the period audited. These evaluation studies were categorised according to the type of report, the approach and **methodologies** employed and the main findings reported in order to identify the major characteristics of the studies underlying the main evaluation exercises such as the 5YAs.

Assessment of stakeholder expectations

From the start of this performance audit there was a firm belief within the Court that areas for improvement could most likely be identified by looking at **international good practice**, both within the EU Member States and beyond.

Therefore, the auditors interviewed around 90 experts identified as **stakeholders in Member States and associated countries** (Czech Republic, Germany, Estonia, Spain, France, Italy, Luxembourg, Netherlands, Austria, Finland, Sweden, United Kingdom and Norway) in addition to more than 60 Commission officials. These interviews were based on a standardised questionnaire and focussed on the experts' perception of the Commission's evaluations, on possible "lessons to be learnt" from research evaluations at national level and their expectations for future evaluations of the FPs.

The audit team then carried out two fact-finding missions in the **USA** and **Canada**. These countries had been selected **as an international comparison group** and more than 65 experts in the field of research evaluation were interviewed.

Finally, **surveys** were carried out **with institutional stakeholders** at the European Parliament (EP) and the Council. The questionnaires were addressed to the members of the EP's "Industry, Research and Energy"(ITRE) committee, which is responsible for research policy and to the Member State representatives in the Council's CREST[4] committee. Most of the questionnaire related to their perception of the Commission's FP evaluation and monitoring activities and, with regard to future evaluations, their expectations and information needs.

External assistance

Given the complexity and methodological difficulty of evaluating research, the Court decided from the beginning to seek assistance from external experts for several aspects of the audit. Following a call for tender, two consultancies ("Technopolis" and "CM International") were

[4] The CREST ("Comité de la Recherche Scientifique et Technique" - Committee for Scientific and Technical Research) is made up of representatives from national authorities who are responsible for the scientific and technological policies of Member States. CREST has an advisory role, informing the Commission and the Council, in particular on subjects relating to the co-ordination of national R&D policies and the monitoring and evaluation of the FPs.

selected to provide support for specific work packages defined in the Court's detailed planning memorandum.

The assistance provided by "Technopolis" consisted of a review of academic literature and a comparative analysis on current trends in research evaluation (carried out by Erik Arnold), input to the design of the audit (Patries Boeckholt) and the participation of Isabelle Collins in the fact-finding missions to the USA and Canada. "CM International"'s contribution is detailed below.

FOCUS GROUPS AS A "SOUNDING BOARD"

Preliminary audit results scrutinised by focus groups

A crucial step in this audit task was the discussion of the preliminary findings, conclusions and recommendations with research evaluation experts from several EU Member States, associated countries, the USA and Canada during a series of facilitated focus groups. The focus groups constituted an integral part of the audit process and were designed to provide an important forum for the **discussion and critical review of the Court's preliminary conclusions**.

Box 2: **Focus groups** are particularly well-suited for obtaining a number of views on the same subject. They bring together a group of individuals with a common interest in the form of a collective interview or a structured discussion in which open-ended, but focused, questions are asked so as to trigger a debate amongst the participants.

The use of focus groups is common in marketing and, increasingly, in politics and opinion polling in order to elicit responses and reveal new perspectives from a group of people held to be representative of consumers or target groups.

The participants need to have an interest in the subject and ideally there should be a mixture of backgrounds. During a focus group session it can be expected that the discussion will stimulate views that, at first, are diverse and even divergent. One key role of the facilitator is therefore to manage the discussion in such a way that common ground can be found and views begin to converge, although full consensus of views is not the aim of a focus group discussion.

The function of the focus groups was not to conduct their own assessment of the Commission's evaluation processes and procedures but rather to comment on and validate the Court's analysis, conclusions and recommendations and, where appropriate, suggest areas where they could be improved. They were therefore aimed at enhancing the quality, relevance and legitimacy of the overall outcome of the audit process.

How was the focus group process organised?

The focus group meetings took place in February 2007 at the Court's premises in Luxembourg. The groups, which totalled around 30 experts, comprised **evaluation practitioners, representatives of national ministries and research organisations, programme managers and academics** selected in such a way as to ensure a balanced view and a mix of nationalities. In addition, representatives of the European Parliament and the Commission were invited as observers. The focus groups were facilitated by an experienced team drawn from "CM International", headed by Meirion Thomas.

All participants were provided with briefing materials, including an **"interim report"** of the Court's preliminary audit findings, conclusions and recommendations, that they were asked to read, study and consider before the start of the meeting (see Figure 2). Given the preliminary nature of the audit conclusions at the time of the meeting, all participants were bound by confidentiality agreements.

The meeting started out with a brief presentation of the auditor's main findings. Then, four sub-groups were convened and were asked to **scrutinise the Court's interim report** and each provide a detailed set of comments and suggestions. Rapporteurs drawn from the participants in each of the focus groups were appointed ahead of the individual group session. In addition, for each group a so-called "ice breaker" was nominated to briefly present his or her personal reflections so as to "kick-off" discussion.

In order to assist in this process and maintain a minimum level of consistency, each focus group was asked to consider a **series of questions** as follows:

- Has the evidence been interpreted appropriately?
- Are the conclusions reached by the Court valid?
- Are the recommendations proposed by the Court appropriate?
- Are there implementation issues or challenges that should be anticipated?

How did the Court use the results of the focus groups?

At the end of the focus group session, the rapporteurs and facilitators met to produce a summary of the discussions in their groups. These formed the basis of a **joint debriefing** attended by the rapporteurs of the four sub-groups, the facilitators from "CM International" and the Court's audit team.

After the debriefing meeting, the external facilitators summarised the verdict of the participants (as presented by the rapporteurs) in a **report on focus group proceedings**.

The audit team carefully considered the comments and suggestions made in this report. In March 2007, the participants received a copy of the facilitators' summary report and an updated version of the Court's "interim report" showing how the text had been modified to take account of the focus group discussions. This **modified "interim report"** was then also sent to the Commission as part of the Court's normal procedure for clearing up the facts (see Figure 2).

The use of focus groups as a sounding board for audit findings and a way of assuring quality before making the results of an audit public was a stimulating experience and certainly an **innovation for the European Court of Auditors** as a public audit institution.

Indeed, in a survey carried out among the focus group participants after the sessions, almost all the respondents strongly felt that they had had the opportunity to express their views and opinions during the focus group sessions. But even more importantly, almost all the participants partly or strongly agreed that the changes made to the "interim report" adequately responded to the comments and suggestions made during the focus group sessions.

Clearing up the facts and the Commission's right of reply

Despite the use made of focus groups in this way, it is emphasised that the findings, conclusions and recommendations published in Special Report N°9/2007 remain entirely the point of view of the Court.

Whilst the auditor and the auditee may disagree on the conclusions and recommendations of a performance audit, there should be no disagreement about underlying factual findings. For this reason, making sure that the facts published in an audit report are correct is of major importance to all auditors, including the European Court of Auditors.

According to common practice among audit institutions, interim observations are therefore sent to the audited body for comment and the validation of the factual findings. In the EU context, these intermediate reports are called "Statements of preliminary findings" (SPF), and the Commission has to provide a reply to these observations within 8 weeks (see Figure 2).

According to the EU Treaty, the Court itself is composed of 27 Members representing the Union's Member States. When the audit has been completed (i.e. the Commission has replied to all SPFs), the Court adopts a **final report for the European Parliament and the Council**. Once finalised, all the Court's reports are public documents.

Initially, a draft final report is discussed and, subject to the modifications agreed, provisionally adopted by the Court. This preliminary report is then sent to the Commission again for verification and comments and the Commission has 10 weeks to reply. After this final clearance procedure, the Court formally adopts the final report, together with the Commission's replies and the replies are published together with the report.

WHAT DID THE AUDIT CONCLUDE?

The Court's Special Report recognises that **evaluating research programmes**, and, in particular assessing their long-term results, **is inherently difficult** and **international best practice is hard to define**. Socio-economic changes are complex and, more specifically, the relationship between a research activity and the outcomes and impacts that are observed is often difficult to trace. Finally, assessing the results of a public intervention in the research field poses a number of methodological difficulties.

While the Commission can point to a sizeable body of evaluation studies, the fact remains that **little or nothing is known about the achievement of programme objectives and the results of the FPs**. This is because evaluations have generally focussed on short-term issues of programme implementation. As a result, the Commission's evaluations were of limited usefulness to policy-makers, stakeholders and even to the Commission itself.

In the Court's view, given the importance of evaluation for programme management and policy-making, the Commission's approach to evaluating the FPs and their constituent programmes needs to be re-examined in view of new political challenges, increased funding, a broadening of the orientation of Community research policy and the recent Commission reform.

In particular, the Court's report calls for the development of a comprehensive evaluation strategy for FP7. The Court also notes a number of respects in which there is scope for the Commission to reconsider its existing organisational arrangements for the evaluation of the FPs.

Specific **recommendations** of the Special Report 9/2007 are summarised below.

Box 3: The Court recommends that:

(i) **intervention logic** should be rendered explicit in future legislation. Underlying assumptions should be explained, the link between scientific and socio-economic objectives clarified and appropriate performance indicators developed;

(ii) a comprehensive **evaluation strategy** should be developed by (and agreed among) the DGs implementing the FPs. In particular, this should entail a consistent approach with regard to the minimum level at which detailed evaluation must take place so as to take account of the specificities of each scientific field;

(iii) consideration should be given to setting up a **joint evaluation office** for co-ordinating the "research DGs'" evaluation activities for the FP as a whole and creating a **system of panels** (and sub-panels) composed of external experts. These panels should be set up sufficiently early in order to provide effective assistance to the Commission, and continue to do so throughout the programming period and thereafter;

(iv) the **data requirements** for evaluation and monitoring should be analysed properly and more extensive use should be made of other existing sources of data. The Commission should also rationalise the **reporting requirements** for participants. Finally, it should draw up a comprehensive **evaluation manual** for the FPs and develop a broader range of **evaluation methodologies and techniques** to be used for evaluations in this field; and

(v) the Commission should establish the **type and scope of evaluation** that can be reasonably expected for the dates specified in the FP7 legislation and clarify how evaluations can be used to adapt programmes ("learning programmes") and what contribution they can make to policy decisions.

CONCLUSION

This paper gives a brief overview of the European Court of Auditors' **Special Report 9/2007** concerning the European Commission's system for evaluating the EU RTD framework programmes. An insight into the background and process of such an audit has been provided along with a summary of the report's conclusions and recommendations.

Hopefully, the extensive consultations undertaken for the audit have helped the report's conclusions resonate with stakeholders and have ensured that recommendations are constructive and practical. The input of all those who participated in the audit in one way or another was greatly appreciated.

The authors of this article believe that the very fact that the European Court of Auditors decided to undertake an audit of the Commission's evaluation system for the FPs is just as important as the report's specific conclusions and recommendations. This is because the audit highlighted the important role that should be played by robust programme evaluation and a proper assessment of results in the research field, one of the most important areas in European policy. We believe that more should be expected from the Commission and, perhaps also, the evaluation community.

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