R&D Value Mapping: A New Approach to Case Study-Based Evaluation*

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Abstract

This study presents an approach to harnessing the power of case studies for research evaluation called R&D value mapping (RVM). *While this method uses case studies in the traditional manner to provide in-depth insights, it also structures case studies through an analytical framework that yields quantitative data and less subjective "lessons learned." When properly applied, RVM can yield an inventory of outcomes and empirical generalizations regarding the determining variables. A particular advantage of the approach is that it not only provides an indication of the type and amount (though not a single numerical index) of outcome, but also gives insight into the reasons outcomes are achieved. Thus, RVM is useful for policy management strategies seeking to replicate success. The specific steps associated with the RVM method are illustrated through studies that have applied the technique.*

The set of analytical tools for assessing the social and economic impacts of R&D has expanded significantly during the past ten years. Not so long ago, evaluation of R&D impacts and technology development seemed equal parts alchemy and vaguely derived numbers. As a result of methodological developments, the numbers are currently derived with a bit more rigor. While alchemy still holds sway, serious evaluations are much more common.

Despite advances in application of such research evaluation techniques as cost-benefit analysis (Averch 1994), benchmarking (Rush et al. 1995) and bibliometrics (Rao 1996), one set of obviously relevant techniques, case studies, has remained somewhat stunted in its development. Case study approaches to research impact evaluation generally have credibility with policy-makers and officials and are popular among evaluators and policy analysts (Kingsley 1993). But with the conspicuous exception of the methodological advances provided by Robert Yin (1994), case study approaches to research evaluation remain fragmented, piecemeal and difficult to aggregate. Case studies, in research evaluation as elsewhere, seem to "tell us more and more about less and less." Case studies provide richness and depth of understanding but, all too often, one is left to one's own devices in trying to determine "what it all means." While case studies can provide important lessons, the lessons depend as much on the interpretive ability of the reader as the science of the evaluator.

The objective of this paper is to outline advances in a new approach to harnessing the power of case studies for research evaluation, an approach that has promise, if successful, of using case studies in the traditional manner to provide in-depth insights; but, at the same time, it may use case studies in an analytical framework that yields quantitative data and less subjective "lessons learned."

The method, termed *R&D value mapping* yields an inventory of benefits and empirical generalizations of the determinants of those benefits and has been applied in several studies (Bozeman et al. 1992; Bozeman and Roessner 1995; Kingsley and Bozeman 1997; Kingsley and Farmer 1997; Kingsley, Bozeman, and Coker 1996). A particular advantage of the approach is that it not only provides an indication of the type and amount (though not a single numerical index) of value, but also gives insight into the reasons benefits are achieved. Thus, R&D value mapping (RVM) is useful for policy management strategies seeking to replicate success.

RVM has much in common with earlier case study-based attempts to assess research but is in many respects a significant departure. As in previous case studies of R&D impacts, RVM focuses intensely on particular projects and the events surrounding them. Case studies "tell a story" about the chronology and events contained within the boundaries of the project, and RVM is similar to traditional case studies in that it yields such a narrative. There is also an expectation that the case studies can contain a richness that goes beyond traditional aggregated quantitative studies to provide insights from detail and nuance. RVM,

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however, seeks to avoid some of the pitfalls of traditional qualitative analysis.

Case studies are faulted as interesting stories, which provide little systematic explanation. The RVM approach, beginning with carefully specified and testable models of causation, as well as a scheme for linking the cases, yields both particularistic and generalizable data. The particularistic information is much like that which is derived from a traditional case. The generalizable data comes from the quantification of elements across cases. Thus, each project "tells a story" and simultaneously gives rise to systematically measured observations.

We do not apply RVM in this paper but instead outline the method and discuss previous and ongoing applications. The objectives of our paper, then, are to articulate the method, compare it to other approaches of R&D impact assessment, and to assess its strengths and weaknesses. We begin by reviewing the use of case studies for understanding the impacts of R&D and technology development.

A Brief History of the Use of Case Study in R&D Impact Analysis

Case study methods, which have been described by some quantitatively oriented social scientists as little better than cultivation of anecdotes (Luukkonen-Gronow 1987), have of late received much attention. Among the many contexts in which case studies have become popular, those in the field of R&D impact analysis have been among the more innovative.

The use of case study methods for evaluations of R&D impacts has been shaped by two research questions: (1) What are the linkages between R&D and economic innovation? (2) Are R&D projects meeting the policy objectives established for the sponsoring organization that mandate linkages between R&D and the economy? Answers to the first question have been the preoccupation of policy-makers since World War II when the impact of science on the welfare of the nation became dramatically clear (Ronayne 1984). Answers to the second question have been the preoccupation of industry and government agencies who must demonstrate the economic benefits of specific R&D projects (Roessner 1988).

Initially, case study was employed in the hope of developing concepts and methods that would allow a more precise understanding of terms such as invention, innovation, technology transfer, or basic, applied, and development research (Ronayne 1984). The ultimate thrust of this research was to develop concepts and methods that would allow a more explicit and thoughtful articulation of the causal relationships that link R&D and the economy (Freeman 1977).

There have been four genre of case studies used in the post-World War II era for examining the impacts of R&D. Three are different forms of retrospective analysis: (1) historical descriptions, (2) research event studies, and (3) matched comparisons. The fourth is a combination of retrospective analysis with other methodologies such as aggregate statistics, peer review, bibliometrics, and econometrics (Logsdon & Rubin 1985). Though the development of these case study types are roughly sequential and build upon the failings of earlier studies, the development of new techniques has not resulted in the obsolescence and retirement of the earlier approaches.

The earliest approach was to conduct *historical descriptions* of the development of a specific technology. The work of Jewkes, Sawers, and Stillerman (1969) is an example of this genre of case study, examining the relationship between R&D and innovation by tracing innovations back to fundamental supporting inventions. Similarly, Carter and Williams (1957) examined the stages in the generation and application of scientific knowledge from basic research to the commercial decision of innovation investment. Though historically informative, this approach did not result in a structured analytic framework with well-defined concepts and methods of measurement.

From the 1960s to the 1970s, a series of massive case study projects were sponsored by government agencies in an effort to understand the linkages between R&D and economic growth. Studies such as Project Hindsight (Sherwin & Isenson 1967) sponsored by the Department of Defense, and the Technology in Retrospect and Critical Events in Science project (TRACES) (IIT 1968), sponsored by the National Science Foundation, advanced the analytic techniques used in retrospective analysis by identifying "research events" in the development of specific technologies. Research events are defined as the occurrence of a novel idea and the subsequent period where the idea is explored. Thus, the technique was to take specific research technologies and divide them into the research events that led to the successful development of the technology. Another development in retrospective analysis was to compare innovations that had been determined *a priori* to be of different types. For example, Project SAPPHO (SPRU 1972) conducted pairwise comparisons of innovations that were successes and failures in terms of commercial diffusion.

The empirical results of these studies dramatically conflicted, reflecting the interests of the organizations that had sponsored the studies (Krielkamp 1971; Mowery & Rosenberg 1982); nor did these studies establish a strong conceptual base from which further research could build (Mowery & Rosenberg 1982). Economic and bibliometric techniques began to replace retrospective case studies as the preferred methods to examine the link between R&D and economic innovation (Layton 1977, Luukkonen-Gronow 1987).

Throughout this period, case study had also been used to evaluate the performance of specific R&D projects within the context of a policy objective. These objectives normally have an implicit, or explicit, assumption that R&D directly affects the economy (Roessner 1988), but the goal of the case study emphasizes evaluation of project performance in preference to developing contributions to theory. Though case studies seeking to establish linkages between R&D and the economy failed in establishing a strong theoretical base, they nonetheless had a significant methodological influence upon case studies emphasizing project evaluations. Evaluation studies have mimicked the retrospective case study designs used to develop theory. For example, a recent case study conducted by Oak Ridge National Laboratory uses a form of retrospective analysis charting the Department of Energy's contribution to the development of several building innovations (Brown, Berry, & Goel 1991).

But the frustration with the findings from case study design also led to a variation in case study research that combines several methodological techniques. As noted above, these multi-method approaches bring together case study with peer review, bibliometric techniques, and econometric analysis under the heading of impact analysis (Logsdon & Rubin 1985). The goal of impact analysis is to look for levels of agreement between the different techniques employed (Nelson 1982; Logsdon & Rubin 1985; Meyer-Krahmer 1988).

Strengths and Weaknesses of Case Study

Yin (1994) has summarized the major strengths and limitations inherent in all case study designs. There are three strengths to case studies. First, this method is very useful for addressing questions regarding how and why a phenomenon behaves. In other words, the findings of case study research reveal a rich detail of information that highlights the critical contingencies that exist among the variables. Second, this method is very useful for exploration of topics when there is not a strong theory to which one can appeal. It is particularly useful for addressing contemporary subjects where there is not a knowledge base to draw upon. Similarly, unlike some quantitative methods, case study is very forgiving to the researchers own learning process of the social phenomenon that is being observed.

Yin (1994) suggests there are three fundamental problems. First is the concern over the lack of rigor of case study research. The thrust of this concern is that the format of case study allows equivocal evidence, or biased views, to influence the directions of the findings and conclusions. This problem grows out of the nature of the data collected, which is often in narrative form and in large volumes of information.

A second problem is that, though case study is useful for ordering information, there is little inherent in the methodology for assessing causality or making scientific generalization. Yin (1994) argues that concerns regarding the lack of rigor of case studies are exaggerated and outlines ways to remedy this criticism. Case study research designs can and do utilize multiple case comparisons (as has been seen in R&D impact evaluations in each of the four quadrants of Table 1). This can strengthen the external validity of studies without sacrificing internal validity. Similarly, researchers develop a framework of analysis for making comparisons across cases with greater rigor than that normally associated with case study.

A third concern regarding case study is that it takes a great deal of time to collect and analyze the data when attempts are made to use case study in a scientific manner addressing the problems of validity and reliability. Relatedly, it is also an expensive method to conduct. The combination of the two reduces the practicality of this method in many research questions.

A variety of innovations have been developed during R&D evaluations to mitigate the weaknesses of case study methods while capitalizing upon the strengths. Kingsley (1993) has analyzed these using a two-dimension typology. The first dimension addresses whether the research question pursues (1) the development of theory relating R&D to social and economic innovation or (2) the evaluation of outcomes in relation to organizational goals. The second dimension distinguishes between the use of case study by the public or private sector. A diagram of this typology, dividing the use of case studies into four quadrants, is provided in Table One. Each quadrant is evaluated according to the following criteria: first, the research question framing the study; second, the case selection method; and third, the analytical methods employed.

Case studies in Quadrant 1 are designed to develop theory regarding the role of the government in supporting R&D. There are relatively few case studies associated with this quadrant. TRACES (ITT 1968) and Project Hindsight (Sherwin & Isenson 1967) are the best known of the genre. This is partially due to the enormity of the task. Those that have been conducted were massive undertakings, requiring years of effort by large teams of researchers (Ronayne 1984). These case studies seek to identify the contributions of R&D to technological innovation with the intention of determining the proper role of government in supporting research. Selection of cases has been determined by the types of technologies with which the sponsoring agency has been working. This type of case study divides each path of technological development into significant research events. The nature of the government's role is described for each of these events.

Case studies in Quadrant II attempt to do a similar type of theory development but apply their efforts to private sector developments of technology. The studies attempt to relate the events leading to a specific technological innovation with the associated industrial structures, organizational structures and managerial practices (Jewkes et al. 1969; Langrish et al. 1972). Histories are developed of technological innovations and matched comparisons are made between those that were successfully commercialized and those that were not. Selection of the cases for study generally are made based upon convenience and access.

Case studies in Quadrant III are conducted as part of a government agency's efforts to evaluate projects that it

Table 1. Typology of the uses for case study for R&D evaluation

	Public Sector R&D	Private Sector R&D
	Quadrant I:	Quadrant II:
Theory-Driven Research	Large-Scale, Research Event Histories	Technology Histories, Matched Comparisons
	Quadrant III:	Quadrant IV:
Evaluation-Driven Research	Social and Economic Impact Analysis	Firm or Industry Impact Analysis

has sponsored (Kerpelman & Fitzsimmons 1985; Logsdon & Rubin 1988). Thus, the research question is narrower, limited to assessing whether the project or program is meeting the policy objective. Generally, studies of this sort have focused upon cases that agency managers have identified as "successful." Three methods are combined with a project development history to conduct the impact analysis: (1) aggregate statistics; (2) production functions; (3) peer review.

Quadrant IV contains private sector evaluations of R&D projects (Levinson 1983; Bard et al. 1988; Utterback et al. 1988). The focus of the evaluation is not directly upon the R&D project but instead upon the commercial performance of the industry or firm. Case selection is generally both opportunistic and focused upon successful projects. The case study usually is comprised of a description of the industry's or the firm's structure, a history of the development of a key technology, and a history of the market for the technology.

The primary strength of these different genres of case studies is that they provide a context for understanding the many contingencies that affect how and why R&D has impacts. However, because the use of case study is constrained in R&D evaluations to a form of retrospective analysis, there has been little progress towards predictive models.

The R&D Value Mapping Approach

In capsule, RVM begins with one or more analytical model that tracks flows of knowledge and specifies possible outcomes of R&D projects. The outcomes are modeled in terms of sequences of events, depicted as a branching model. Each step in the model might be either the final outcome for the project or a preliminary stage to the next step. Thus, the sequences might include the following steps:

- ***(step 1)*** project completed (yes, no), [if yes...]
- ***(step 2)*** results disseminated outside the laboratory (yes, no), [if yes...]
- ***(step 3)*** results used by an individual or organization not affiliated with the lab (yes, no), [if yes...]
- ***(step 4)*** product developed from results (yes, no), [if yes...]
- ***(step 5)*** product marketed (yes, no) [if yes...]
- ***(step 6)*** outcomes [for example, sales from product, or other measures of benefits, costs, and disbenefits].

Measuring the variety of benefits and disbenefits that may result from a project specifies a second dimension of R&D outcomes. As an illustration, Table 2 provides a potential list of the commercial benefits from R&D projects. The potential benefits will, of course, vary according to the objectives of projects. However, there is nothing inherent to the RVM approach that ensures that outcome measures are limited to benefits. For example, Kingsley, Bozeman, and Coker (1996) examined the impacts of failures to transfer technology from R&D projects.

RVM involves measuring a variety of hypothesized project attributes (e.g. resources devoted to a project; the number of industrial participants; disposition of IPR) against the branched patterns of outcomes. By conceiving projects in terms of the progress of their results along certain branched alternatives (the steps given above), it is possible to develop predictive models of the factors related to project outcomes vis-a-vis those possible branched alternatives. Essentially, what factors relate to the ultimate path position, the final step, of the project?

After the analytical models and associated hypotheses have been developed, data gathering in RVM is much the same as for a traditional case study. Case selection is also driven by the criteria relevant to the model. The selection process can lead RVM to an embedded case study research design because there are multiple units of analysis, i.e., R&D projects, stemming from a single institutional setting. However, there is no requirement in the RVM method that cases share a common institutional frame. Data sources include personal interviews, documentary evidence, records and files. The resulting data can, indeed, be fashioned into traditional "thick description" cases.

In addition to the results of traditional case studies, RVM provides an analytical device resembling an empirical explanation in quantitative social science. RVM provides quantitative data from cross-case analysis. In some instances the measurement approach is similar to most quantitative studies. Thus, for each case, indicators are developed for such variables as amount of funding for the

Table 2. Illustrative impact assessment table

Impact Type	High Impact	Some Impact	No Impact
Established new company or joint venture			X
Enhanced company's technical capabilities or know-how	X		
Developed new commercial product			X
Developed new commercial process		X	
Improved existing product			X
Improved existing process		X	
Licensed or patented technology or software		X	
Created new jobs	X		
Set industry standard and standard enabling R&D			X
Influenced company's R&D agenda		X	
Company terminated planned process or product (advantageously)		X	
Provided technical knowledge used by company's suppliers or customers			X
Enhanced human capital and skills at company	X		

project, numbers of personnel devoted to the project and, on the benefit side, such variables as estimated monetary benefits and numbers of personnel receiving advanced training. Somewhat of a departure, however, is the attempt to use dummy variables (i.e., 0,1) to measure qualitative aspects of the cases. Thus, it is possible to quantify such variables as whether the lab's technology transfer office was involved in the project (0=not involved, 1=involved), whether a diffusion plan was developed at the outset of a project (0=developed later or not at all, 1=developed at outset), or whether the results of the project required the user to develop new manufacturing processes (0=not required, 1=required). By combining these variables, both the traditional interval-level variables and the dummy variables for the presence/absence of a project attribute, a series of causally relevant independent variables are developed.

These independent variables are then analyzed in terms of the sequential models developed at the outset. This assessment is made both in terms of the step reached in the branching model and the benefits (or disbenefits) that occur. RVM is similar to other case survey techniques whereby multiple coders score individual cases and resulting scores are subjected to an inter-coder reliability analysis (Bullock & Tubbs 1987; Larsson 1993; Wolf 1993). Case scores are then categorized for pattern-matching both within groups of cases and between case groupings.

The research procedures of RVM can be summarized as follows:

1. Develop sequential, but nonlinear, branching model(s) of the flow of knowledge from research to exhaustive set of outcomes.
2. Develop propositions about causal factors related to those outcomes.
3. Develop indicators of costs and benefits from projects and project-related outcomes.
4. Select cases on the basis of factors specified in model and hypotheses.
5. Gather data on cases.
6. Organize data by writing traditional case studies
7. Develop quantitative database by coding the case studies according to the model variables.
8. Validate data coding conventions (e.g. inter-rater reliability indices).
9. Use resulting quantitative data in connection with models, determining (through contingency analysis or dynamic programming) the relation of independent variables to knowledge flows, project outcomes, and benefits and costs.

An early stage in the application of RVM requires assessing the outcomes of projects. This initial assessment can be provided by program managers, principal investigators or others involved with the project. Table 2 also provides an illustrative assessment table, but as knowledge of the projects develop, more sophisticated assessment techniques become appropriate.

A key to the successful application of RVM is to begin with theory-based models depicting the flow of impacts

Table 3. R&D Impact Assessment Techniques; their Applications and Strengths

Method	Technical Needs	Validity/ Reliability	Summative/ Formative	Resources	Time Needed
Qualitative					
Case study	H	H/L	S/F	H	H
Focus group	M	M/L	S/F	L	L
Peer review	L/M	M/M	S/F	M	L
Content analysis	H	H/H	S	M	M
Mixed					
R&D Value Mapping	H	H/M	S	H	H
Delphi Panels	M	M/M	S/F	M	M
Quantitative					
Bibliometric	H	M/H	S	M	M
CBA/ROI	H	M/M	S	M	M
User Survey and Quest.	H	H/H	S/F	M	M
Benchmark	M	M/M	S/F	M	M
Quasi-Experiment	H	H/H	S	H	H
Forecasting	H	L/M	S/F	L/M	M
Portfolio Analysis	M	H/M	S/F	L	L
Network Analysis	H	H/H	S/F	M/H	H
Input-Output	H	L/H	S/F	M/H	M/L
Operational Audit	L	M/M	F/S	L	M
Systems/Flow Analysis	L	M/M	F	L	L
Indicator Systems	L	H/H	F/S	L	L
Industry Analysis	M	H/M	S/F	L	L
GIS/Diffusion	H/M	H/M	F/S	M/H	H/M

H – High M – Medium L – Low S – Summative F – Formative

from projects. Since RVM is iterative, it is assumed that these models will be revised continuously during the project in order to inculcate learning. For example, in a study of R&D projects sponsored by the New York State Energy Research and Development Authority, two models were employed in describing the sequence of possible outcomes. A technology absorption model identified the stages in the adoption of a technology by the organizations that participated in the R&D contract. The transfer model identified stages in the movement of technology from a R&D project to adoption by external organizations that did not participate.

Prototype Applications of R&D Value Mapping

Bozeman and colleagues developed the fundamental components of RVM in a study of 31 applied research and development projects (Bozeman et al. 1992; Bozeman & Kingsley 1997; Kingsley, Bozeman, & Coker 1996; Kingsley & Farmer 1997; Kingsley 1995) and then further refined the approach by applying it to a set of cases focusing on projects at DOE laboratories (Roessner, Bozeman, Donez, & Schofield 1996; Bozeman & Donez 1996; Roessner 1996). The more recent prototype applications focused on three cases—Brookhaven National Laboratory Superconducting Wire (Bozeman & Donez 1996); Stanford Linear Accelerator Thin Film Deposition (Roessner, Bozeman, Donez, & Schofield 1996); and Oak Ridge National Laboratory Ceramic Whiskers (Roessner 1996). A more ambitious and large-scale project, focusing on as many as 50 case studies of projects funded by the Department of Energy's Basic Energy Sciences Division, is now underway.

The Methodological Locus of RVM

As with other evaluation approaches, it is important to understand the position of RVM in connection with other available approaches to assessing R&D and technology development impacts. Table 3, adapted from Bozeman, Shapira, and Youtie (1996), provides an approach to "locating" and assessing RVM in connection with other available R&D impact evaluation approaches.

While it is not our purpose in this paper to provide a systematic assessment of the methods used for R&D impacts analysis (for more detailed treatment see Bozeman & Melkers 1994 and Bozeman, Shapira, & Youtie 1996), it is useful to succinctly describe each of the criteria presented in Table Three and to provide our assessment of RVM in connection with those criteria.

In the first place, RVM is one of the few available techniques that is, at the same time, both qualitative and quantitative. Since it requires as input detailed cases, the cases themselves provide a strong qualitative element. However, since the cases are used to develop indicators and to test explicit models using a sequential path analysis, there is inexorably a quantitative element to RVM.

The criterion "technical needs" refers to the degree of technical training and expertise required for performing the method. A disadvantage of RVM is that the technical needs are extremely high, requiring not only case analysis skills but skills in modeling and, importantly, skills in methodological development. Since there is as yet no template for RVM, its application is not in the least mechanical.

"Validity" refers to the power of the method to ascertain the causal relations in hypotheses about program effects; "reliability" refers to test-retest correspondence. Compared to other available approaches, RVM holds great promise with respect to validity. The combination of in-depth analysis and application of systematic (if not invariant) method means that the inferences from RVM analysis are much better grounded than for most techniques. RVM can also be strong from a reliability perspective. By having several coders review the same large body of case studies inter-coder reliability can be statistically assessed.

"Summative" means the evaluation is chiefly for final program effects; "formative" means findings are useful for program improvement in an ongoing program. RVM is useful for both summative and formative evaluation but is best suited to summative evaluation simply because there must be time for project impacts to occur. This is not to say that it is irrelevant to formative analysis—some project impacts can be observed early on. Moreover, it is by its very nature a "learning technique," requiring adjustment and refinement of models and method as more and more is learned about project outputs and impacts.

The major disadvantage of RVM is that it is inherently resource-intensive. The notion of quantitative treatment of cases depends fundamentally upon having a sufficient number of cases (usually at least 30) to permit quantitative analysis and application of inferential statistics. The requirements are not quite so formidable as they might seem given the possibility of mixing in-depth "base cases" with "mini-case" studies that focus only on the particular variables examined in the RVM models. Even under the best of circumstances this is an approach that requires considerable resources. Similarly, the amount of time required for RVM is considerably greater than for most other approaches.

In sum, the RVM approach is best viewed as "high investment-(potentially) high return." It requires considerable resources, considerable technical and methodological expertise (including some receptivity to methodological innovation), but its expense and effort is redeemed by detailed knowledge of cases (as with most case study approaches) as well as a systematic set of explanations of impacts.

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