Public Value Mapping of Science Outcomes: Theory and Method

A Monograph of the Public Value Mapping Project of the Center for Science, Policy and Outcomes

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Executive Summary

The Public Value Mapping Project of the Center for Science, Policy, & Outcomes seeks to develop conceptual tools and measures enabling a better understanding of the impacts of scientific research on desired social outcomes. This monograph summarizes progress in developing theory and method for assessing the public values aspects of science outcomes.

The critical problem for understanding the social impacts of science is that we have no satisfactory tools for understanding how these largest-scale social impacts occur and, by implication, few useful guideposts for "managing" their occurrence.

A maintained assumption in our study is that traditional R&D evaluation and planning are inappropriate for analysis of public Big Science and its social impacts, and the reason is simple: *In national science policies seeking grand scale social impacts, science is only one of the players and not always the most important one.* Any approach that focuses on scientific inputs and outputs and resources developed and expended by scientists but fails to focus on other important actors will result in an incomplete or misleading inferences about social outcomes and their causality. Science is not a self-contained institution and very few if any of the major social transformations occur because of science. Social outcomes and transformations do not occur because of scientific change but because of the social apparatus for marshalling scientific change.

"Public Value Mapping of Science Outcomes" (PVM) is not a traditional R&D impact evaluation method, but rather a conceptual tool for developing systematic understanding of the multiple determinants of social outcomes and the role of science as part of the web of institutions, networks, and groups giving rise to social impacts. The key questions in PVM are these:

- Given a set of social goals and missions, ones in which science is intended to play a major role in bringing about desired social outcomes, are the strategies for linking and mobilizing institutions, network actors and individuals viable ones?
- Is the underlying causal logic of program or mission sound?
- Are the human, organizational, and financial resources in place to move from science and research to application to desired social outcome?

The theory supporting PVM analysis is a "churn" model of knowledge value and innovation (Bozeman and Rogers, 2002) and, especially, the idea that science outcomes are best understood in terms of the "knowledge value collectives" and "knowledge value alliances" (Rogers and Bozeman, 2001) that arise to generate, develop, and use scientific research. By this view, it is vital to understand research outcomes and the availability of scientific and technical human capital to produce research, but it is also important to understand other parties to the "knowledge value collective" including, for example, government and private funding agents, end users, wholesalers, equipment and other scientific resource vendors, and so forth. The "churn" theory begins with the premise that science and scientists have little ability to provide social outcomes, either advantageous or disadvantageous ones, apart from other social actors.

We illustrate PVM, an approach that is applicable to any large-scale, public scientific mission, in the context of a scientific mission that is obviously important, universally recognized, and well underway: providing accessible treatments for cancer, especially breast cancer. The primary policy context studied initially as a PVM application is the Georgia Cancer Coalition (reported in a companion monograph [Gaughan, 2002]). The Georgia Cancer Coalition (GCC) is the largest state-funded cancer research initiative, with more than $60 million of state funds provided in just its first year (Greenblatt, 2001, p. 38). The GCC is an

excellent target for analysis, especially using a method focusing on inter-institutional relations and roles for end users, in this case medical services consumers. It brings together scientists and scientific resources, but also a wide array of potentially enabling institutions, networks and individual actors. The approach contrasts, and deliberately so, with recent national cancer prevention and treatment efforts.

Public Value Mapping draws from two bodies of theory, one normative, the other explanatory. The normative theory framework is "public failure theory", and approach to understanding those public values not easily reflected in market-based indices or economic cost-benefit terms. Public failure theory asks "what criteria are useful for gauging social impacts, apart from whether the values are served by government or the market?" The "churn model" of innovation is used as an explanatory theory, applied to map public values from so-called "knowledge value collectives".

PVM's Normative Theory: Public Value Failure

One of the reasons why there has been less attention than one might expect to systematic assessment of large-scale public science and research policy initiatives and their impacts is that in the U.S. the market-based model of science policy assumes tacitly that "good research" will automatically be used in the market and to everyone's benefit. There is much evidence that the linear model is in need of re-examination and that the road from research to impact is neither as straight nor as clean as many have long assumed. Often market failures and public failures have little correspondence to one another. Even when market and public outcomes are in desired alignment, implications for the distribution of benefits and costs and access to positive outcomes of science are rarely clear-cut.

Unfortunately, when one commits to understanding research impacts and, at the same time, one foregoes standard economic production function models or cost-benefit applications, one has little relevant theory to use as a guide. One of the aims of Public Value Mapping is to develop public value theory while, at the same time, seeking to build public value evaluation methods.

The theory of "public value failure" is available elsewhere (Bozeman, 2002; Bozeman and Sarewitz, 2002) and, thus, requires no extended treatment here. Only a brief overview is required. The goal of public value theory is to develop a model in many respects analogous to market failure, but one that eschews concerns with price efficiency and traditional utilitarianism in favor of a public value focus. Similar to market failure theory, public value theory provides criteria for diagnosing public failure (and identifying public successes). With the public value model, the key policy question becomes: "If the market is efficient is there nonetheless a failure to provide an essential public value?"

Public value failure theory provides an alternative set of criteria for assessing social choice and outcomes, ones not relying on commodification. These include such factors as time horizons, sustainability and conservation values, benefit hoarding, and ability to aggregate interests.

PVM's Explanatory Theory: The Churn Theory of Knowledge Value and Innovation

A key assumption of PVM is that when Big Science is employed as a means of achieving social goals, science is only one of the institutions and actors determining outcomes and not always the most important one. The view of socially embedded science corresponds closely to the "churn theory" of knowledge value and innovation (e.g. Bozeman and Rogers, 2002). The term "churn theory" was chosen because "churn" implies no particular direction of outcome (e.g. linear) and no imputation of scientific progress. Churn recognizes that change can occur but that the outcomes from chance may be positive, negative, neutral, or, most likely, mixed.

In the churn theory, a key issue is the capacity of science to produce desirable outcomes. This capacity is a function of the character and capabilities of whole fields of science (not just projects or programs) and the effective working of the knowledge value community. The knowledge value community includes not only the first-order producers of scientific outputs, but also others who have a role in bringing science to use, including, for example, resource providers (e.g. grants officials, venture capitalists), developers, entrepreneurs, equipment producers, suppliers and vendors of every stripe, interest groups and advocacy groups, and, of course, the consumer or end user. All such parties are viewed as part of the knowledge value collective because each is producing knowledge, using it or enabling its use. Without some understanding of the KVC and of the ability to produce new uses of knowledge, known as "scientific and technical human capital", it is not possible to develop a deep understanding of the relationships between science and outcomes

Three interrelated dimensions capture the effectiveness of a KVC. The dimensions relate to the ability of KVC to produce knowledge and to translate knowledge into social impacts and, thus, provide starting points for PVM analysis.

Growth. If a KVC's growth is stunted, so is its potential for producing new uses and establishing new translations. Naturally, measures of growth must take into account the developmental level of a KVC: different growth rates should be expected from emergent configurations than stable ones. A host of growth indicators are of interest. Among other factors, one must examine absolute growth, rates of growth and magnitudes of growth; each is important and likely to capture important information about the KVC.

With slight adjustments in growth measures one captures completely different meanings. If we measure the *size* (absolute numbers of users and principal uses) of a KVC we can determine the *magnitude* of domain (i.e. 50 uses). If we measure the *first differences in growth* over a given period we can determine "base anchored" changes of magnitude (from 50 uses to 100 uses). If we measure *rate of change in growth* (a 150% growth rate over two years) we capture a "base free" proliferation. Each of these is important and tells us something different, interesting, and germane to the evaluation of KVC's. Drawing on these simple measures we can evaluate KVC's as:

1. *Low Incidence-High Incidence*: they produce more or less principle uses.
2. *Expanding-Contracting*: by looking at first difference we can determine whether a KVC is getting smaller or larger and we can determine the magnitude in terms of numbers of uses.
3. *Rapid Growth-Slow Growth*: by looking at rates of change we can determine the pace of uses, ultimately, perhaps shedding light on KVC life cycles (not unlike diffusion curves).
4. *Diversifying-Simplifying:* by looking at the variety of uses it makes of others' information products versus the relative variety of its own products used by others. Strictly speaking this would not be a measure of growth of the KVC itself but it would indicate its ability to create value out of many sorts of inputs and the ability to provide diverse sources for others to create value. There are four possible classes of KVCs according to this measure: a) simple input to simple output: a *simple transformer*; b) diverse input to diverse output: a *rich transformer*; c) simple input to multiple output: a *multiplier*; d) multiple input to simple output: a *filter*.

Fecundity. We can evaluate a KVC's *fecundity*, its ability to generate use. In part, fecundity is simply a matter of the growth of the network (since growth and use are definitionally dependent). But fecundity is the power to generate uses rather than the uses themselves. Possibly, fecundity is not directly observable, but good indirect measures can be obtained:

a) *Longevity*: the ability of a KVC to sustain itself over a long period of time, maintaining a high rate of new principle uses.
b) *Reach*: the KVC has greater reach if its problem domain is greater in scope (e.g. Callon, 1997, p. 27). A KVC which generates uses in highly diverse and not easily connected scientific problems, disciplines, technologies is said to have great "reach".
c) *Generative Power*: the KVC which has the ability to spawn new KVC's (i.e. user groups which, while stimulated by the problem domain of the focal KVC, detach themselves and attack new problems enabled by work in the initial KVC). While it is not an easy matter to measure precisely just when a new KVC has emerged from an old one, this seems at least a possible task and certainly a rewarding one.

S&T Human Capital. An assumption implicit in the foregoing, but which we have not yet stated explicitly, is that knowledge embodied in human beings is of a higher order than dis-embodied knowledge contained in formal sources (e.g. technological devices, scientific papers). S&T human capital is the sum total of scientific, technical, and social knowledge and skills embodied in a particular individual. It is the unique set of resources that the individual brings to his or her own work and to collaborative efforts. Since the production of scientific knowledge is by definition social, many of the skills are more social or political than cognitive. Thus, knowledge of how to manage a team of junior researchers, post-docs and graduate students is part of S&T human capital. Knowledge of the expertise of other scientists (and their degree of willingness to share it) is part of S&T human capital. An increasingly important aspect of S&T human capital is knowledge of the workings of the funding institutions that may provide resources for one's work.

The S&T human capital framework assumes:

1. Science, technology, innovation, and the commercial and social value produced by these activities depends upon the conjoining of equipment, material resources (including funding), organizational and institutional arrangements for work, and the unique S&T human capital embodied in individuals.

2. While the production function of groups is not purely an additive function of the S&T human capital and attendant non-unique elements (e.g. equipment), it resembles closely an additive function. (The "missing ingredient" in such aggregation is the salubriousness of the fit of the elements to the production objectives at hand.)

3. Most important, the S&T human capital model of effectiveness is enhancing the ability of R&D groups and collectives to produce knowledge. Thus, the object of evaluation is best viewed in terms of capacity, not discrete product.

S&T human capital can be examined at any level of analysis, including the individual, the project, and the organization; but it can also be considered in connection with a knowledge value collective. The key issue in the latter focus is: what are the S&T human capital endowments contributing the KVC (and, implicitly, are they adequate for the social goals expectations that have been established for the KVC)?

To summarize, PVM draws from disparate theoretical strands and prescribes methodological and operational approaches that are fluid, drawn together only by a foundation in historical analysis and case studies, a pragmatism in use of quantitative methods and a commit-

From Theory to Method: PVM Procedures

The inset below provides a rudimentary summary of PVM procedures. But the procedures flow from a set of operating assumptions.

Assumptions

1. PVM can be either prospective (analyzing planned or projected research activities), "formative" (analyzing such activities as they are occurring), or "summative" (evaluating activities and their impacts after they have occurred).

2. PVM focuses at the level of the "knowledge value collective" and examines the social impacts it engenders. An important methodological aspect, then, is to provide a specific, operational definition identifying the KVC of interest. The KVC includes the scientists contributing knowledge to the target issue of interest (e.g. genetic engineering of crops, breast cancer prevention and treatment) as well as institutional and stakeholders shaping social impacts.

3. In focusing on the KVC, PVM studies? both the capacity of the KVC (its potential to create new knowledge and applications) and the outcomes it engenders. Analysis focuses, then, on the KVC's scientific and technical human capital, guiding policies, its network linkages and institutional configurations, the resources in the environment and available to the KVC and, in general, the ability to deploy successfully the knowledge produced by the scientists and technicians working in the KVC.

4. PVM seeks to take into account the highest order impacts of activities (i.e. broad social aggregates) and, thus, ultimately ties evaluation to social indices and social indicators.

5. PVM is multi-level in its analysis, seeking to show linkages among particular program activities of an agency or institution, activities of other agencies or institutions, relationships- either intended or not- among various institutional actors and their activities.

6. PVM assumes that all programmatic and research activities entail opportunity costs and, generally, the goals and outcomes achieved are necessarily at the expense of other possible goals and outcomes that could be achieved by alternative uses of those resources.

7. PVM is guided by a "public value model of science outcomes" rather than a market-based or market failure model. PVM explicitly rejects evaluation and assessment based on commodification of research values and outcomes. Market prices are viewed as weak partial indicators of the social value of research and research outcomes. Even as a partial indicator, market value is considered in terms of not only magnitude but also distribution and equity criteria.

8. Since market value is eschewed in PVM and since generally agreed upon public values are rarely available, PVM anchors its outcomes values in a wide range of criteria derived from diverse sources including:[1] official, legitimated statements of policy goals; [2] goals implicit in poorly articulated policy statements; [3] government agencies' goal statements in strategic plans and GPRA documents; [4] values

derived from public budget documents. While value expressions of politically legitimated policy actors are examined first, public values may be supplemented with statements of value in opinion polls; official policy statements by relevant NGOs; policy statements of public interest groups.

9. Research techniques employed in PVM depend upon the needs and possibilities afforded by the context of its application. The only technical approach used in each application of PVM is the case study method. In-depth case study and historical analysis is always an element of PVM. Accompanying research techniques will be chosen in terms of their relevance to the particular PVM science and outcomes domain. (Examples of some of the research techniques that may be employed include: Survey research, polling, and questionnaires; focus groups; analysis of aggregate data about outputs and impacts; expert opinion, including structured expert opinion such as Delphi technique, contingent value analysis; patent and citation analysis.)

10. PVM is designed explicitly to be prescriptive and uses its data and results to provide information about program planning, design and implementation.

PVM Operations

Step 1: Provisionally, identify research and social outcomes domain.

Step 2: Identify measurable public values

Step 3: Sort values and their relationships (means-ends, hierarchies)

Step 4: Establish metrics for public value

Step 5. Identify research domain and researchers, map the “research ecology”

Step 6. Identify target problems of researchers and research programs, ultimately linking to social indicators.

Step 7. Develop causal logic models relating public value statements and research and program activities

Step 8. Identify research techniques appropriate for testing causal paths from research to public value at various outcome levels, culminating in aggregate social indicators.

Step 9. Using causal logic models, develop hypotheses about causal paths from research to public value, specifying expected relationships between research variables, control variables and social outcome variables.

Step 10. Use research techniques to test the hypotheses and, when necessary, identify alternative outcome models.

Step 11. Write PVM summary including findings about models relating research programs and activities to public value and social outcomes, results of hypotheses concerning causal logic models.

Step 12. Develop prescriptive model and recommendations for enhancing contribution of research to public value.

ment to causal analysis ("mapping") of the chain from knowledge production and use to social impact. The proof of the approach will be in accompanying applications, including the breast cancer research case provided in a companion monograph. PVM is, at this stage, a "pilot" assessment method, subject to revision as the various applications determine what is and is not possible with respect to data availability, analytical strategies and time required for the intensive analysis suggested by the approach.

Public Value Mapping of Science Outcomes: Theory and Method

I. Introduction: Research Evaluation and its Limits

Public Value Mapping in Broad Concept

The Public Value Mapping Project of the Center for Science, Policy, & Outcomes is motivated by the need for conceptual tools enabling a better understanding of the impacts of scientific research on desired social outcomes. This monograph summarizes progress in developing theory and method for assessing the public values aspects of science outcomes.

There is near universal acceptance of the assumption that science is one of the most important, perhaps even the most important, means of achieving the fundamental collective goals of societies, including economic growth, national security, health, and life itself. To be sure, most wary denizens of the 21st Century are well aware that science is not a cure all and that science sometimes contributes to social and individual "bads" as well as to positive outcomes. But, nonetheless, when societies confront challenges or seek new opportunities, it is to scientists and institutions of science to which they most often turn. We hope that scientists (and engineers) will develop technological innovations that keep our economies afloat. We hope that scientists will help solve prodigious problems of environmental degradation, even realizing that past scientific outcomes have contributed to some of those problems. We hope that scientists will provide the medical research breakthroughs that will help us prevent or remedy many of the illnesses, diseases and agents of deterioration that are the scourges of human existence. We hope that scientists will develop the security devices and systems that will protect us from our human enemies. In short, we have placed tremendous burden of expectation on science and scientists and, from decades of results, we have a good reason to believe that our expectations, demanding as they are, are not entirely unrealistic.

Science's burden of social expectations is accompanied by ample resources provided chiefly through tax dollars. Most scientific funding, research, and development (especially development) still comes from the private sector; and private sector R&D investments are larger than public ones, at least in the United States. But, generally, private sector research is narrow and industrial research seeks benefits captured by the firm (Crow and Bozeman, 1998). Often the private sector plays an important role in large-scale, science-intensive social objectives but, in most such cases, much of the private sector research work is financed by government.

When the public ties its social goals to science, the public investment in science often is redeemed, sometimes well beyond our expectations and our imaginations; witness the "Green Revolution," space travel, and medical transplants. In other instances, billions of tax dollars are spent for science and the desired social outcomes are not achieved. Witness the Nixon-era War on Cancer, the massive 1970's synfuel programs, and "star wars" missile defense system, otherwise known as the Strategic Defense Initiative. And, of course, major social impacts often accrue as unexpected, sometimes positive "byproducts". For example, we do not currently think of the Internet as a means of providing secure networks in case of thermonuclear attack nor do we think of the medical applications of Magnetic Resonance Imaging (formerly Nuclear

Magnetic Resonance Imaging) as the private preserve of the physicists who developed early techniques. Similarly, when World War I era scientists were developing chemical weapons they could not have known that this early work with mustard gas would later prove a key link to developing chemotherapy treatments for cancer (Benderly, 2002).

The critical problem for understanding the social impacts of science is that we have no satisfactory tools for understanding how these large-scale social impacts occur and, by implication, few useful guideposts for "managing" their occurrence. We have a long history of developing techniques for planning, managing, and evaluating industrial R&D projects and some of these have been adapted to the public sector, generally with little success, especially with respect to "Big Science" efforts.[1] Industry R&D evaluation approaches (and the public R&D evaluation methods based on them) are characterized by a focus on "Small Science", an effort to internalize returns, narrow project and resources boundaries, and, in most instances, some attempt to commodify or monetize the results. By contrast, the Big Science efforts by which we pursue social goals are characterized by an effort to disseminate returns, extremely broad networks, loosely connected with few boundaries, and, in many instances, their goals have nothing to do with commodities or monetized results and, indeed, efforts to determine a dollar cost-benefit are often misleading. As a result of the mismatch of intent and method, most of what we know about large-scale science and technology efforts' social impacts is derived from historians. These accounts are often quite useful but generally do not provide guidelines for prospective analysis, program design, or even evaluation. Historians are masters of the idiosyncratic.

A maintained assumption in our study is that traditional R&D evaluation and planning are inappropriate for analysis of Big Science and its social impacts and the reason is simple: *In Big Science, seeking grand scale social impacts, science is only one of the players and not always the most important one.* Any approach that focuses on scientific inputs and outputs and resources developed and expended by scientists but fails to focus on other important actors will result in incomplete or misleading inferences about social outcomes and their causality. Science is not a self-contained institution and very few if any the major social transformations occur because of science. Social outcomes and transformations are often fed by science; they are not caused by science. Medical breakthroughs, technological innovations, and weapons systems require not only sophisticated technology delivery systems (Ezra, 1975), but interconnected social institutions functioning effectively. The history of innovation is the history of science, but also of engineering, corporate finance, marketing, capital markets, management and, most important, end of stream consumers. The history of medicine is the history of science but also of public health, social stratification, income security, intellectual property law, patients, patients' rights and advocacy groups.

"Public Value Mapping of Science Outcomes" (PVM) is not a traditional R&D impact evaluation method, or even really a method at all, but rather a conceptual tool for developing systematic understanding of the multiple determinants of social outcomes and the role of science as part of the web of institutions, networks, and groups giving rise to social impacts. It is not a case study method, except in the broadest sense, because the "case" generally is broad-scale social change not amenable to the boundaries and particular qualitative rigors generally associated with case study method. It is not history because it is an applied conceptual tool, seeking general lessons in a way that most historiographic approaches do not and, most important, PVM is as appropriate for prospective study and contemporaneous analysis as for retrospective study.

The key questions in PVM are these:

- Given a set of social goals and missions, ones in which science is intended to play a major role in bringing about desired social outcomes, are the strategies for linking and mobilizing institutions, network actors and individuals viable ones?

- Is the underlying causal logic of program or mission sound?
- Are the human, organizational and financial resources in place to move from science and research to application to desired social outcome?

The theory supporting PVM analysis is a "churn" model of knowledge value and innovation (Bozeman and Rogers, 2002) and, especially, the idea that science outcomes are best understood in terms of the "knowledge value collectives" and "knowledge value alliances" (Rogers and Bozeman, 2001) that arise to generate, develop, and use scientific research. By this view, it is vital to understand research outcomes and the availability of scientific and technical human capital to produce research, but it is also important to understand other parties to the "knowledge value alliance" including, as examples, government and private funding agents, end users, wholesalers, equipment and other scientific resource vendors, and so forth. The "churn" theory begins with the premise that science and scientists have little ability to provide social outcomes, either advantageous or disadvantageous ones, apart from other social actors. Thus, it is important to understand the characteristics of knowledge producers but also of those providing the resources for knowledge production and the users of knowledge and technology. If one takes this perspective, a useful one for Big Science, then it is clear why traditional approaches to R&D evaluation are wanting.

We illustrate PVM, an approach that is applicable to any large-scale, public scientific mission, in the context of a scientific mission that is obviously important, universally recognized, and well underway: providing accessible treatments for cancer, especially breast cancer. The primary policy context we examine is the Georgia Cancer Coalition. The Georgia Cancer Coalition (GCC) is the largest state-funded cancer research initiative, with more than $60 million of state funds provided in just its first year (Greenblatt, 2001, p. 38). Other funds have been provided by the federal government and private sources, especially the Avon Products Foundation which has given $7.5 million to date. The GCC is an excellent target for analysis, especially using a method focusing on inter-institutional relations. It is, essentially, a "knowledge value alliance", set up to pursue expressly articulated goals in connection with cancer treatment and prevention. It brings together scientists and scientific resources, but also a wide array of potentially enabling institutions, networks and individual actors. The approach contrasts, and deliberately so, with recent national cancer prevention and treatment efforts. National cancer efforts, funded and coordinated chiefly by the National Cancer Institute, have focused to a large extent on basic and near basic research with limited clinical trials and limited inter-institutional cooperative strategy. More and more dollars have supported more and more research in the national cancer effort but in some respects the results have been disappointing. Not only do many cancer rates seem unaffected by this level and type of effort but egregious health care disparities remain, despite explicit policies and intent to alleviate these disparities and to provide more equal access to cancer treatment and prevention resources. By contrast, the GCC approach is inter-institutional and network-based, involving not only scientists but public health officials, health care advocates, insurance companies, pharmaceutical companies and linked research facilities. In design, at least, it is a different "path" to the desired social impact.

In a companion monograph (Gaughan, 2002) PVM is used as a conceptual tool to understand the GCC path and to contrast this approach to the one that has been pursued by the NCI. This is largely a prospective study inasmuch as the GCC has been underway for only one year and the results and social impacts will occur in streams for the next several years. PVM is used by Gaughan not only to identify the path planned by GCC but to map that plan against real outcomes that accrue in the short- and intermediate-term and, since this is an instrumental approach, to suggest alternative paths and alternative causal logics when useful. Before providing more detail on the PVM approach, we begin with a brief overview of public sector research evaluation trends in the U.S.

B. Public Sector Research Evaluation in the U.S.

As late as the early 1980's, the research evaluation field was one with few practitioners, mostly focused on economic evaluation of industrial firms' internal rate of return. In the United States, evaluation of *public* R&D impacts was not a field at all, but rather an agglomeration of fragmented, largely isolated works, many unpublished.[2]

One recently uncovered "early artifact" focusing on evaluating publicly funded and performed R&D is Salasin, Hattery and Ramsay's *The Evaluation of Federal Research Programs* (1980). Their intention was to "identify useful approaches for evaluating R&D programs conducted and sponsored by the federal government" (p. 1) and in pursuit of that objective they interviewed more than two hundred experts in evaluation or R&D management. The resulting monograph cited 49 papers, including exactly one journal article (Rubenstein, 1976) and one book (Andrews, 1979) focusing explicitly on evaluating government-sponsored R&D. Other "relevant" citations were studies of scientists' citation patterns, R&D management approaches, government agency handbooks, studies in social program evaluation and discussions of peer review of scientific papers. The monograph identified four problems endemic to evaluating government R&D impacts, including (1) lack of a straightforward definition of effectiveness; (2) multiple and competing objectives; (3) problems in aggregating products and results, especially across programs; and (4) reconciling political and scientific measures of success- a list that would work just as well today.

This pioneering monograph concluded with a problem identified by a great many of the more than 200 experts consulted: "It is not clear that it is possible to assess research quality based on the immediate outputs of a research project (e.g. reports or journal publications)" (Salasin, Hattery and Ramsay, 1980: p. 62). The authors point out that benefits of research may occur over long periods of time and at different rates and with different values according to the user. They also suggest that one performer's research impacts cannot be viewed separately from others', at least not if there is an interest in charting the magnitude of intellectual and social change wrought by research. Most important, failing to recognize these problems might lead to "the very real danger that evaluation mechanisms could 'straight-jacket' a research program" (p. 63).

Today, studies and methods of R&D evaluation have proliferated. In 1980, only one journal gave any serious treatment to government R&D evaluation, the then-infant *Research Policy*. Since that time the number of research specialists and the number relevant journals dealing with the topic have increased dramatically. But most of the problems identified in the Salasin, Hattery and Ramsay exploratory monograph still exist, particularly the problems associated with a focus on discrete R&D outputs. Today, as in the early 1980's, approaches to evaluating public R&D remain quite similar in structure and logic to those for evaluating private R&D. This is especially true inasmuch as both public and private approaches then focus on particular research products and their narrow-gauge impacts. Today, as before, research evaluation focuses more on economic impacts than social impacts. Now that the last decade in the United States has seen an interest in more ambitious use of research evaluation and in increasing knowledge about the broad social and environmental outcomes flowing from research, new approaches to research evaluation are required.

This paper suggests a new approach, Public Value Mapping (PVM), one that goes beyond analysis of discrete outputs of particular research products. PVM is a method focusing on public value, particularly the impacts of public sector performed or sponsored research (but also in relation to other performers) on the social changes envisioned in public programs and policy statements. The method and its assumptions are reviewed in detail below, particular with reference to a prototype illustration, research aimed at ameliorating the incidence and traumatic impacts of breast cancer. But the PVM method is designed to be applicable to any field of research or community of researchers and to any accompanying set of policy goals and social outcomes.

Before articulating the PVM theory and method, we consider briefly some of the factors contributing to the need for a new type of research evaluation and some of the pre-cursor developments making a new approach possible.

B. Government R&D Evaluation Rising

Despite the fact that little attention has been given to a broader more integrated approach to analysis of science's social impacts, attention has been given to more tractable problems in assessing narrow-gauged, more self-contained government R&D investments and impacts. One indicator of increased interest among United States policymakers in assessing the returns, benefits, and impacts of public support for research is the proliferation of documents, conferences and official publications addressing that topic. An early bellwether was the Congressional Office of Technology Assessment's 1986 Technical Memorandum focusing on improving research funding decisions through the use of quantitative techniques associated with the concept of investment (OTA, 1986). The OTA review covered economic and output-based, quantitative measures used to evaluate R&D funding. Economic methods included macroeconomic production functions, investment analysis, and consumer and producer surplus techniques. Output methods included bibliometric studies, patent counts, converging partial indicators, and science indicators approaches.

In 1993, Bozeman and Melkers (1993) edited *Evaluating R&D Impacts: Methods and Practice*, an R&D evaluation primer with contributions by leading authorities on such topics as case studies of R&D projects, rate of return on R&D investments, co-word analysis, bibliometric approaches, and operations research approaches, among others. This book, which was aimed for a relatively technical, limited audience volume, generated a surprising level of interest due chiefly to the fact that the topic of public R&D evaluation was wedging its way onto the public policy agenda. About the same time, the Critical Technologies Institute of the RAND Corporation published a report prepared for the Office of Science and Technology Policy reviewing methods available for evaluating fundamental science (Cozzens, et al., 1994) and this effort, too, received a good deal of attention.

Each of these works provided diverse approaches to evaluation but most falling within an economic framework. Economic assessments of R&D generally fall into two basic categories: production function analyses and studies seeking social rates of return. Production function studies assume that a formal relationship exists between R&D expenditures and productivity. Social rate of return studies attempt to estimate the social benefits that accrue from changes in technology and relate the value of these benefits to the cost of the investments that produced the changes of interest.

In the United States, professional evaluation of government R&D has been dominated by microeconomic models and their attendant tools, especially benefit-cost analysis. These approaches have a strong appeal, focusing as they do on discrete science and technology outputs such as the number of articles or patents produced in R&D projects, jobs created by technology transfer programs, and contributions of technology-based economic development programs to regional economies. Evaluation rooted in neoclassical economics seems to hold forth promise of "harder" more rigorous analysis and, thus, matches well the policymaker's need for justification of expenditures. Rationalist, "new public management" approaches to government performance, such as is embodied in the Government Performance and Results Act, seem quite compatible with evaluation based on microeconomic models, yielding a monetary value.

While economics-based approaches often prove useful, the focus on the discrete products of R&D projects places significant limitations on evaluation. In the first place, the fact that such approaches work best when there are crisp boundaries (e.g. a single R&D project) is itself a major limitation. Second, the tendency to have science and technology products disembodied from the individuals and social context producing them provides an unrealistic overlay to evaluation. Third, such evaluations tend to be static. To be sure, many cost-benefit studies model streams of benefits over time but they rarely take into consideration the mutability of the "products" evaluated, much less the changes in the persons and institutions producing them. Fourth, product-oriented evaluations tend to give short shrift to the generation of capacity in science and technology, and to the ability to produce sustained knowledge and innovations.

Input-Output Research Evaluation

While the field of research evaluation has made great technical strides, these have chiefly been with the dominant input-output framework. Figure One depicts the general approach.

Figure One: Simple Input-Output Model for Research Evaluation

Within the relatively simple framework, a great deal of complexity resides. In the first place, the research inputs, such factors as research funding, scientific skills, and equipment are not so easy to identify as they might seem, especially in the fluid boundaries of research enterprises. Similarly, while almost everyone recognizes the importance of the organizational and management context to research — indeed the field of R&D management is devoted entirely to this topic — measuring organizational and managerial influences remains a challenging science laced with a great deal of art. Furthermore, even if one examines narrow-gauge outputs, measurement and conceptualization is problematic and tying those outputs to specific management and resource variables is always difficult.

Within this basic framework, such approaches as cost-benefit analysis and cost-effective and operations research permitted the quantification of research evaluation, which generally focused on commercial criteria and examined outputs from industrial R&D. This same basic framework was also used, however, for academic research evaluation, with the important difference that the outputs were less often evaluated by economic criteria and generally focused on imputed scientific quality, often using publication type or citation as a surrogate for quality. Citation and co-citation analyses became more and more sophisticated and useful with the development of citation databases, powerful computers, and tailor-made software.

Research Impact Evaluation

The problem with the approaches developed under this general input-output model is not a problem of technique but, rather, a limitation of the model itself. While there are still many studies performed today that use this simple input-output set of assumptions, more and more research evaluation is concerned with *impacts* of the outputs of science and technology (see Figure Two).

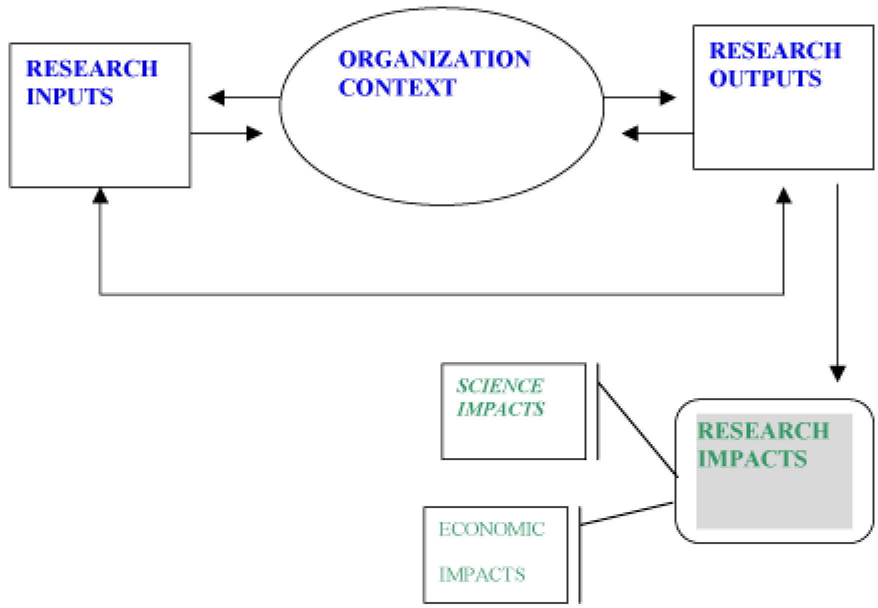


Figure Two: Impacts Model for Research Evaluation

Even today, relatively few studies have gone beyond output to actually measure impacts. Most of the studies that do examine impacts focus either on impacts on science or commercial impacts. As we see from Figure Two, such impact studies generally focus on either economic impacts or impacts on scientific fields. For example, impact studies that have been performed to date tell us about such impacts as, in the case of economic impacts, job creation, new business creation or business expansion, new product development or marketing or, in the case of scientific impacts, development of new fields or sub-fields of science or contributions to solving puzzles or gaps in scientific theory. Both the economic-based and the science quality-based impact studies have been quite useful for their purposes.

What is in extremely short supply is evaluations of the social impacts of research. Obviously, the economics-based studies generally have important social implications and, in a sense, economic impacts are social impacts studies of a sort. But if one is concerned about those social impacts of research that are not easily expressed (or are misspecified) as economic value, then there are very few such studies and there has been very little headway in developing appropriate research evaluation methods.

A New Approach: Public Value Mapping

Public Value Mapping (PVM) is not so much a research evaluation approach as a means of assessing or forecasting social impacts of large-scale programs and policies of science, ones aimed expressly at broad social goals. PVM is a set of methods, anchored by theory, and focused on public value created by science and the institutions and stakeholders requisite for moving from creation of scientific knowledge to social impact. Thus, PVM recognizes that such actors as agency grant officials, foundation officers, equipment vendors, entrepreneurs, elected officials, retailers, interest groups, customers, and end users all have potential to shape the social impacts of science.

In developing Public Value Mapping, we are attempting to create a valid, practical, outcomes-based approach to broad-gauge evaluation of science impacts. What is missing from research evaluation and, almost by definition, from program evaluation is an evaluation method that moves beyond the program level to focus much more broadly on the ability of sets of programs, agencies, and even sets of agencies to achieve broader social impact missions. The primary objective is to develop the PVM approach, outlining its basic elements and, especially, its theoretical underpinnings in knowledge value theory, and when possible, assessing its technical strengths and weaknesses.

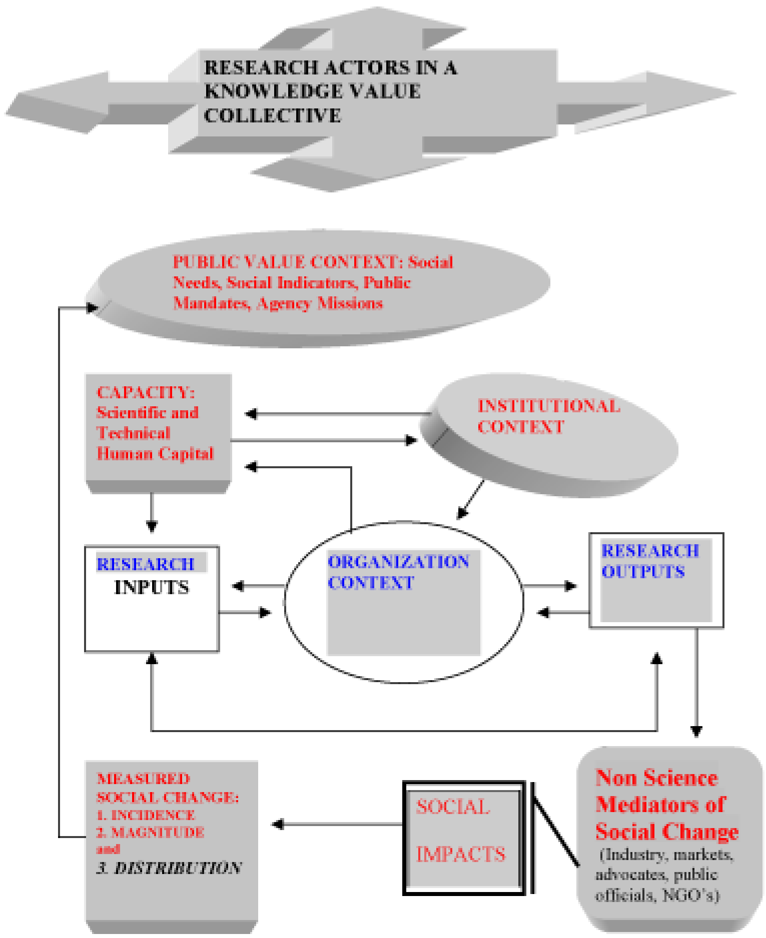
Public Value Mapping draws from two bodies of theory, one normative, the other explanatory. The normative theory framework is "public failure theory," an approach to understanding those public values not easily reflected in market-based indices or economic cost-benefit terms. Public failure theory asks "what criteria are useful for gauging social impacts, apart from whether the values are served by government or the market?" The "churn model" of innovation is used as an explanatory theory, applied to map public values from so-called "knowledge value collectives." Each is explored in some detail before, but after a brief overview of Public Value Mapping.

Public Value Mapping: An Overview

As in the previous discussion of fundamental models of evaluation, we can consider the overall framework of assumptions for Public Value Mapping. It is an impact model, similar in many respects to the impact model in Figure Two. But, as we see in Figure Three, PVM includes some concerns not generally addressed in research evaluation. In the first place, research outputs, impacts, and organizations are considered in terms of their role with the environment for research. This includes other researchers and research institutions and their work, but also such contributors as funding agencies, users of research and other stakeholders affecting the demand for research, research resources, and controls on research. The PVM approach, thus, considers the capacity to do research, including especially the pool of "scientific and technical human capital" (Bozeman, Gaughan and Dietz, 2001), the actual "scientific and technical human capital" (S&THC) available and deployed by the research unit and the impacts of the research unit and activity on the development of further S&THC. Equally important, PVM examines as part of a knowledge value collective not only those who themselves produce scientific knowledge but the long chain of institutions and actors who enable the transformation of knowledge into uses and social impacts.

In Figure Three we see that the focus is on social impacts rather than scientific and economic impacts (though, of course, none of these can be considered in a vacuum). In considering the measure of social change resulting from the research, we consider not only the impact incidence and magnitude, but also the *distribution* of impacts. This is a factor not often considered in any form of research evaluation but important for a number of reasons including the fact that a great deal of public policy and many public policy goals statements explicitly seek to encourage widespread or equitable distribution of social outcomes in general and, specifically, research outcomes.

Figure Three: Public Value Mapping Model for Research Evaluation



C. Research Value and Public Value

Recent studies produced under the Research Value Mapping Program have tried to address some of the usual limitations of evaluations of the impacts of publicly-funded research and have pioneered some methods useful for the broader analysis of public value. These Research Value Mapping (RMV) studies (e.g. Rogers and Bozeman, 2001; Bozeman and Rogers, in press; Bozeman and Rogers, 2001; Bozeman, et al., 2000), based in part on intensive, comparative case studies of research communities, explicitly address organizational and managerial factors and incorporate measures of the value of tacit knowledge and of the creation and diffusion of human resources. The RVM studies, in brief, focus on the *capacity* generated by publicly funded research rather than the discrete outputs and, further, the RVM studies seek to characterize entire research communities rather than just research projects.

The RVM research is chiefly interested in examining scientific fields' and research communities' progress in generating new scientific and technical uses for knowledge (and provides and accompanying theory of research value [Bozeman and Rogers, in press]). According to this "churn" theory of knowledge value, new scientific knowledge has value in its uses, rather than in the economic transactions accompanying those uses. For decades, economists have known that much of the value of research, especially so-called basic research, is not fully captured in prices. Our theory of use-and-transformation goes farther, suggesting that economic valuation of knowledge, while useful in a practical way, is not especially useful for understanding the significance and value of that knowledge with respect to its many uses, only some of which are likely to be accompanied by any sort of obvious economic transaction (for elaboration of this theory see Bozeman and Rogers, in press).

The primary purpose of Public Value Mapping is to understand the social impacts of research, its public value as opposed to its economic productivity or even its theoretical and explanatory contributions. The fundamental question with RVM is "how can we best understand the value of scientific knowledge and its applications including, especially, the ways in which we enhance capacity to create new knowledge, innovation and new uses for knowledge?" PVM, by contrasts, asks, "What is the social impact of research? How does it affect quality of life?" Public value is defined in terms of those outcomes in which the entire society has a stake, including such factors as environmental quality and sustainability, health care and healthy longevity, and provision of basic needs such as housing, food, heating and cooling, and so forth. Since many of these issues depend of distributional questions and not just the ability to produce technologies and commodities, PVM is concerned not only with positive social outcomes, but with equity of social outcomes and, related, access to the benefits produced by research.

Despite the somewhat different foci of RVM and PVM, with the former being more concerned with the capability to produce knowledge and the latter with the social impacts of the knowledge produced, they have much in common. Including:

1. Both approaches seek means of valuing research outcomes not relying on the prices or market value of knowledge. In particular, there is a concern with capacity for producing knowledge and new uses of knowledge.
2. Both approaches assume that the character of knowledge producing, using and consuming communities are important to an understanding of outcomes.
3. Both approaches assume fluid boundaries and focus on discrete knowledge products or programs, as well as organizations, institutions and their connections with one another.
4. While both approaches have theory underpinnings, some common to the two approaches, both approaches are strongly oriented to evaluation.

II. Normative Public Value Theory: Public Values and Public Failure

A. The Need for Public Value Mapping- Economic Valuation and Social Outcomes

PVM origins are need-driven but also take advantage of methodological developments that have occurred relatively recently in the field of public research evaluation. The need for PVM arises from the fact that existing approaches to evaluating research, while extremely powerful for some questions, are not sufficient to tell us much about the causal impacts between research (and research communities) and social outcomes. Many approaches to research evaluation seek to understand the quality of research and the factors affecting quality of research. Many of these studies either assume that "good things" will happen from quality research or the social and economic impacts of research are just not their focus. Other approaches are very much concerned about downstream impacts of research but frame those questions almost entirely in terms of economic impacts. Thus, these studies focus on topics such as the relation of research to commercial technology development, the role of research in technology transfer or the contributions of growth to economic productivity. To be sure, these economic impacts all have significant and ubiquitous effects of social factors, public value and quality of life, but economics-based approaches usually stop short of measuring social outcomes.

Public officials and other parties to science policy have for some time recognized the need for a means of following the causal paths of research and research outcomes all the way to their points of social impact. But much less attention has been given to the social outcomes and public value impacts of research than to economic impacts. This is understandable. Tracking research outcomes to their point of social impact is a much more difficult task than the task of linking research to economic impact. There are two reasons for this greater difficulty. In the first place, it is a longer causal link and, other things being equal, the longer the causal link the more over-determined the causal model. In many cases social outcomes of research continue to accrue well after the most important economic transactions have occurred. If we consider the economic transactions that have been the focus of traditional studies, the ones of greatest importance are costs of producing the knowledge, the sale of the knowledge, costs of developing knowledge (either into technology or reshaping technology), costs of production and, of course, pricing and profit. But many of the most important social impacts occur well after these points and include, for example, negative externalities that may result many years later, access and equity issues and the social relations among knowledge producers and users. These issues have not generally been within the purview of R&D economics or the economics of research evaluation.

In their classic treatment of the convergence of politics and economics, Dahl and Lindblom (1953, 161-168) contemplate reasons why economics centered on choice and allocation is a central problem for the discipline. As they note, "(h)ow different this situation might have been had economists felt the same enthusiasm for defining an optimum distribution of income as for an optimum allocation of resources, if they had pushed with vigor the equalitarian notions that some of them believed their cursory explorations in ideal or preferred distribution forced upon them" (Dahl and Lindblom, 1953, 163). Dahl and Lindblom go on to explain the attraction of economists to choice and allocation questions as owing to several factors, including the fact that choice and allocation questions lend themselves to the construction of mathematical models through which maximization problems could be precisely examined. One of the reasons why economic approaches seem to have less utility for understanding social impacts of research than for any of a wide variety of issues related to science, research, and its impacts is that so many questions of social impact have so much to do with distributional impacts and so little to do with efficiency.

Unfortunately, when one commits to understanding research impacts and, at the same time, one foregoes standard economic production function models or cost-benefit applications, one has little relevant theory to use as a guide. One of the aims of Public Value Mapping is to develop public value theory while, at the same time, seeking to build public value evaluation methods. While this may not be an optimal approach in every respect, there is little choice. Such public value and public interest theory as exists usually is not sufficiently grounded or developed analytically to serve as even a beginning point for evaluating the social outcomes of research.

B. Public Value Mapping and Public Value Theory

While the correspondence between Public Value Mapping and public value or public interest theory is only a rough one, quite unlike the correspondence of economics-based research evaluation and economic theory, there is at least a framework and set of criteria used as a backdrop to PVM. Bozeman's "public values failure" theory, developed more broadly as a means of thinking about the meaning of public value in the context of public policy, is the theoretical touchstone for the PVM work (Bozeman, 2002).

The theory of public value is available elsewhere (Bozeman, 2002; Bozeman and Sarewitz, 2002) and, thus, requires no extended treatment here. But a brief overview is helpful. The goal of public value theory is to develop a model in many respects analogous to market failure, but one that eschews concerns with price efficiency and traditional utilitarianism in favor of a public value focus. Similar to market failure theory, public value theory provides criteria for diagnosing public failure (and identifying public successes). The key question is not so different from the one asked years ago by one of the inventors of the market failure paradigm, Francis Bator (1958): If we assume that economics provides a powerful, well-articulated, and often useful approach to analyzing allocation of goods and service among sectors, are there respects in which it "may not do?"

Public values failure occurs when neither the market nor public sector provides goods and services required to achieve core public values. A public value approach changes the discussion of public policy by making government (and public values) something other than a residual category or an issue of technical efficiency in pricing structures. A fundamental assumption of the model is that market failure actually tells us little about whether government should "intervene." With the public value model, the key policy question becomes: "If the market is efficient is there nonetheless a failure to provide an essential public value?"

To some extent, the public failure model begs the question of just what is a core public value. There are many ways one could deal with this issue. For example, one could rely on "basic needs" (Pigou 1920; Rawls 1971) or sustenance, cultural values distilled from history of cultural expressions of a variety of sorts, public opinion results and plebiscite. But, as we see below, the approach used in PVM is formalistic, relying on public policy missions and statements as an expression of public value.

The market failure approach to analyzing allocation of goods and services is widely used despite its inability to identify "core economic value" (money being only a convenient symbol for value). As a diagnostic tool, the public value model requires no greater specificity than does the market failure model. To be sure, the public value model is not premised on anything similar to the abstraction of a perfectly competitive market, nor does it have the convenient symbol of value, monetary indices. But neither does the logic of market failure depend on the entirely unrealistic assumptions of pure rationality and perfect information or the unrealized ideal of a perfectly competitive market. The fact that market failures are ubiquitous and perfect competition virtually unknown, has not undercut the use of the market failure model's general criteria (Faulhaber 1987). Similarly, the lack of consensus on particular public values should not greatly diminish the use of the public failure model in identifying issues for policy deliberation and public dialog.

C. Public Value Criteria

Public value failure occurs when those values identified as core public values are not reflected in social outcomes, either those resulting from the market, government action, or both. Several criteria are suggested as public value failure. To some extent, these criteria mirror the thinking of market failure. The criteria are presented in Table 1.

Table One: Public Value Failure Criteria (from Bozeman, 2001)

Public Failure	Failure Definition	Illustration
Mechanisms for values articulation and aggregation	Political processes and social cohesion insufficient to ensure effective communication and processing of public values	Combination of U.S. Congress' seniority system and noncompetitive districts leading, in 1950's, to legislative bottlenecks imposed by just few committee chairs who held extreme values on civil rights, national security and other issues.
Imperfect monopolies	Private provision of goods and service permitted even though government monopoly deemed in the public interest	Private corporations negotiating under-the-table agreements with foreign sovereigns
Benefit hoarding	Public commodities and services have been captured by individuals or groups, limiting distribution to the population.	Restricting public access to designated public use land.
Scarcity of providers	Despite the recognition of a public value and agreement on the public provision of goods and services, they are not provided because of the unavailability of providers.	Welfare checks are not provided due to the lack of public personnel or failures of technology for electronic checking transactions.
Short time horizon	A short-term time horizon is employed when a longer-term view shows that a set of actions is counter to public value.	Policy for waterways that consider important issues related to recreation and economic development but fail to consider long-run implications for changing habitat for wildlife.
Substitutability vs. conservation of resources	Policies focus substitutability (or indemnification) even in cases when there is no satisfactory substitute.	In privatization of public services, contractors have to post bond-ensuring indemnification, but provide inadequate warrants for public safety.
Threats to subsistence and human dignity	The core value of subsistence is violated.	Man-made famine, slave labor, political imprisonment.

D. Public Value Failure and Science: An Illustration

Let us consider an example from the criterion “benefit hoarding.” A classic market failure problem is externalities, or spillovers. The costs and benefits of externalities thwart attempts at efficient pricing and result in market failure. Similarly, a public values failure occurs when there are public domain benefits — benefits that should be distributed freely throughout the population — which are for some reason not distributed. This can occur because of benefit hoarding — a group or segment of the population has managed to siphon benefits that are, by their nature or by custom, public domain. In such cases, the fact that a market structure has developed, whether an efficient one or not, is irrelevant and perhaps insidious.

A particularly interesting instance of benefit hoarding that cuts across income and class lines pertains to agricultural R&D and the “terminator gene” plant seed innovation (Lambrecht 1998). The technology works in three major steps: (1) borrowing a seed-killing toxin from another plant, genetic engineers insert it into the genome of a crop plant; (2) in order to breed enough generations of the crop to produce a supply of seeds, scientists also insert blocker DNA that suppresses the production of the toxin; (3) before the seeds are sold they are immersed in a solution that induces the production of an enzyme that removes the blocker, (4) after the seeds are planted and the crop matures, the toxin is produced, killing the new seeds the plants carry. Farmers who want the same crop line the next year must thus buy new seed.

Currently, about 1.5 billion farmers, ranging from subsistence farmers to giant corporations, winnow one year's seed to produce the next year's crop. This practice has been employed, uninterrupted, for more than 12,000 years. One could infer that agricultural subsistence relies on the practice. Even were the terminator seed to prove a great market success (now unlikely due to public outcry against it), it could remain a prodigious public failure, hoarding benefits of seed replication for persons of means. Arguably, terminator seeds sacrifice potential for human sustenance to the ability to levy efficient pricing on a good (derived, second generation seeds) that should not be priced at all. The basic point is this: the market efficiencies and economic value related to the terminator gene are not acceptable indicators of the public value of the R&D and the resulting innovation.

Environmental issues provide some of the best illustrations of problems of market failure approaches to public policy and research evaluation. These limitations are perhaps most compelling with respect to the sustainability of ecosystems (Toman, Pezzey, and Kratkraemer 1995). Standard economic accounting tends to focus on marginal well being, paying heed to the substitutability of resources and limited heed to the irreversibility of diminished but substitutable resources. Risk is perceived in terms of efficiency and, indeed, is defined in cost benefit terms as applicable to forests as to consumer goods. Indeed, much of cost-benefit analysis emerged in response to needs to value natural resources and public works (Krutilla and Eckstein 1958). However, ecologists and some economists (e.g. Victor 1991; Krutilla and Fisher 1985) have begun to note considerable faults in marginal cost benefit accounting for natural systems. In the first place, standard economics tends to deal well with efficiency criteria but poorly with conservation issues. Economics tends to search for substitutes for depletable assets and, if the assets are depleted and harm occurs, to indemnify with monetary assets.

The limitations of market failure and microeconomics-based research evaluation are especially evident in ecological issues, but the fundamental points of public value theory are as relevant to other domains of research and research outcome. Indeed, early applications of public value theory and PVM include not only such topics as species depletion (Corley, 2001), but also breast cancer research, energy R&D, and the new science of nanotechnology.

III. Explanatory Public Value Theory: The "Churn Theory of Innovation" and the "Knowledge Value Community"

The gaps in explanatory theory of science outcomes is not so large as the gap in normative theory, but, nonetheless, the decades of progress in R&D economics, sociology of science, and science studies has yielded relatively few works relevant to the macro-assessment of Big Science impacts. Systematic analysis of science outcomes has proceeded slowly, in part because most approaches to evaluation or planning tend to focus exclusively on the science and its specific projects and practitioners giving little or no attention to the many institutions and actors that help bring science into use. As mentioned in the introduction, a key assumption of PVM is that when Big Science is employed as a means of achieving social goals, science is only one of the institutions and actors determining outcomes and not always the most important one. Science is not a self-contained institution and very few if any the major social transformations occur because of science. Social outcomes and transformations often are fed by science; they are not caused by science.

In addition to public value theory, another theoretical framework employed to understand science and social outcomes is the "churn model" of knowledge value and innovation and its explanation of "knowledge value collectives" (e.g. Bozeman and Rogers, 2002; Rogers and Bozeman, 2001). The term "churn theory" was chosen because "churn" implies no particular direction of outcome (e.g. linear) and no imputation of scientific progress. Churn recognizes that change can occur but that the outcomes from chance may be positive, negative, neutral, or, most likely, mixed. The standard definition of churn, "a violent stirring; to shake or agitate with continued motion" (Webster's Unabridged Dictionary, 1979, p. 324) captures the social dynamics of scientific knowledge quite well. A churn model of knowledge value is coincident with the radical changes in knowledge use (and thereby value) one witnesses in society. To extend the metaphor, scientific knowledge resembles the churning of cream into butter — the constituent elements are stirred until a qualitative change results. The qualitative change provides new uses of knowledge, not necessarily better ones (as butter is not inherently superior to cream).

In the churn theory, a key issue is the capacity of science to produce desirable outcomes. This capacity is a function of the character and capabilities of whole fields of science (not just projects or programs) and the effective working of the KVC. The KVC includes not only the first-order producers of scientific outputs, but also others who have a role in bringing science to use, including, for example, resource providers (e.g. grants officials, venture capitalists), developers, entrepreneurs, equipment producers, suppliers and vendors of every stripe, interest groups and advocacy groups, and, of course, the consumer or end user. All such parties are viewed as part of the knowledge value collective because each is producing knowledge, using it, or enabling its use. Without some understanding of the KVC and of its ability to produce new uses of knowledge, known as "scientific and technical human capital," it is not possible to develop a deep understanding of the relationships between science and outcomes. By analogy, we expect that an automobile (science) can be employed to take us from Los Angeles to New York (outcome), but the nature of the trip, the trajectory and the success of the trip depend on a host of enabling factors such as a supply of workable automobiles, resources to procure and automobile, fuel, roads, maps, insurance, trained drivers, road standards, rules and conventions, and so forth. When science pursues a new path, a skilled driver is not sufficient to ensure a desired final destination.

KVC Fundamentals

The discussion of KVC presented here draws heavily from Bozeman and Rogers (2002) but adds to it. Their original theory is not designed for application, but many of the criteria for KVC operations have implications for application and these will be examined here and expanded upon.

Scientific and technical knowledge does not contain its consequences and potential in itself. It depends on those who pick it up and use it to determine its value (Fuchs 1993). Economic valuation is one means of indirectly representing value-in-use. Economic valuation can tell us the price of knowledge and can estimate the market value of knowledge. These are useful indices but in some respects problematic. In cases where the market is not an efficient allocator of value — as is so often the case with scientific knowledge — economic valuation leaves much to be desired. When the discrete product is less important than the investment in capacity, human capital and scientific potential, knowledge of prices, even shadow prices, tells us little. To be sure, economists have made considerable headway in measuring hedonic value and contingent value (e.g. Mitchell and Carson 1989; Evans, 1984; Freeman, 1982), including the value of scientific projects (Link, 1996). But it is the very reliance on monetizing value that explains the limits of economic approaches to assessing scientific knowledge.

The churn theory of scientific knowledge is a theory of use-as-value. Economic valuation generally provides a precise and distorted reflection of knowledge value. The churn model trades precision and measurement convenience for clarity and reach. Before more fully articulating the churn model, it is useful to clarify our use of "information" and "knowledge."

<u>Information:</u> Descriptors (e.g. coded observations) and statements (e.g. language-based synthetic propositions) concerning empirically-derived observations about

conditions and states of affairs in the physical world and the real of human behavior.

Knowledge: Information put to use in furtherance of scientific understanding (i.e. empirically-based, generalizable explanation of states of affairs and behavior) or in the creation, construction, or reshaping of technological devices and processes.

Scientific or technical information relates to knowledge through interpretation. In itself, information has no meaning, and hence no actual value; it suffices that any actor in an R&D context believes a piece of information has scientific or technical meaning. Meaning is attributed to information when it is used. Use is the criterion by which knowledge is gauged.

Economic assessments of scientific knowledge, whether grounded in cost-benefit reasoning, production function analysis or political economy theory, begin with one fundamental, generally unexamined assumption: the standard for knowledge valuation is price in an open market. To be sure, economists labor mightily to cope with widely recognized problems related to the economic valuing of knowledge, including, most conspicuously, the spill-over and free-rider problems occurring as a result of the joint consumption properties of knowledge (one person's use generally does not diminish its availability and, often, its value to others). But these practical limitations of economic valuation tend to be viewed not so much as a limitation but a spur to developing allocation theories that take them into account. The analytical difficulties that the nature of the "commodity" (scientific knowledge) sets for economic measure and valuation theory are acknowledged by all, but rarely is there much discussion of the difficulties economic valuation sets for the commodity and its translations.

An imputed advantage of a use and outcome based theory is that it provides a framework for analysis of capacity, specifically, the capacity possessed by particular scientists and technologists (their "scientific and technical human capital" (Bozeman, Dietz, Gaughan, 2001), as embedded in the social networks and research collectives producing scientific and technical knowledge. Rather than focusing specifically on discrete projects (the usual realm of cost-benefit analysis) or national economic productivity accounting, our alternative focuses on capacity within fluid, dynamic research collectives.

B. The Core Assumption of the Churn Model: "Use-Transformation-Value"

In the churn model, knowledge is valued by its use and its outcomes. Uses and value are equivalent. Information without use is information without value. Once put into use, information becomes knowledge and, perforce, has value. The appropriate "metric" for value is as diverse as the aspirations of curiosity and decreasing the drudgery of labor.

Knowledge (information-transformed-in-use) gives rise to new information encoded in inscriptions (e.g., presentations, papers, procedures, techniques, blueprints, skills, and so on). This new information has no value until (unless) it is, in its turn, put into use. Information may lie fallow and valueless. Or, it may be used, either by its initial creators or by other individuals, known or unknown to the initial creators. As the information is used (producing new knowledge) it takes its place in a cycle of unpredictable periodicity, a cycle which may or may not lead to new uses and, thus, further information and perhaps, in another cycle of use, new knowledge. In each instance, as information is used and, thus, by its application transformed into knowledge, discernible value is created.

C. The KVC, Science Outcomes and Capacity

In using the KVC model as a theoretical framework for public value mapping, two key concepts stand out as especially important: the “knowledge value collective” and “scientific and technical human capital.” An easy way to think of the two is that scientific and technical human capital is the potential for scientific solutions to social problems and the knowledge value collective is the set of networks and institutions that move science from an individual and small group enterprise, to knowledge development and dissemination and, ultimately, social outcome. Since science, technology, and its application are inherently social processes, the scientific and technical human capital of the individual contributes capacity to networks of knowledge creators and users, i.e. the KVC. The concepts S&T human capital and KVC are important in an applied sense because they are useful in actually assessing the movement from science to outcome. Together, they tell us about the capacity to produce outcomes, the tools for producing outcomes, the possible pathways to outcomes, and the relationships among knowledge producers and users.

D. Properties of the Knowledge Value Collectives

A knowledge value collective (KVC) is a set of individuals connected by their production and uses of a body of scientific and technical information. As users of information, the KVC confers value to the information. It is a loosely coupled collective of knowledge producers and users (e.g. scientists, manufacturers, lab technicians, students) pursuing a unifying knowledge goal (e.g. understanding the physical properties of superconducting materials) but to diverse ends (e.g. curiosity, application, product development, skills development).

Any particular KVC is composed of information/knowledge users who reshape information into new packages of knowledge (including technology, which we view as a physical embodiment of knowledge). The size of a KVC varies enormously from just a few individuals to thousands or more. Typically, the size of the KVC will depend on such factors as general awareness of the body of knowledge, the breadth of its uses, the skills required to obtain and apply information, and the support apparatus required for transforming knowledge into use. There is no requirement that particular members of a KVC interact, know one another or even be aware of one another; the only requirement is joint use of a body of information (and, in their use, creation of knowledge value).

The term “collective” has been used in many different ways in the social sciences and even within social studies of science. Here the term is used in the lexical sense, in the first definition of the *Webster’s Unabridged Dictionary* (1983, p. 367) as “common possession or enjoyment; as in a *collective* of goods.” Our usage is exactly as that primary usage, the common possession and enjoyment of information.

In trying to understand public value outcomes from science, there are several reasons to speak of *collectives.* The term *network* could convey much of the same meaning but it is useful to avoid the many layers of meaning one must peel away from *network* (e.g. Callon, 1997; Bidault and Fischer, 1994; Carley, 1990; Valente, 1995). Since KVC theory draws to some degree from each of these quite disparate sources it seems easiest to avoid confusion among the many meanings of network by just avoiding the term altogether. A second reason for using the term “collective” is to denote a primary interest in a given set of actors: scientists and engineers. Hagstrom used the term “scientific collective” and provided a reasonably tidy operationalization. While the term is used in much the same sense as Hagstrom, the knowledge value collective is not limited to scientists. The KVC includes all “first order” users of knowledge, persons who either use knowledge to create additional information (including technology), who support the use and application of knowledge or who are self-conscious end users. The KVC does not include second order knowledge users, those who uses the knowledge or its embodiment (e.g. technology) without seeking to fundamentally add to or reshape the knowledge or create new uses. Thus, one who plays a VCR, operates a robotic arm or simply reads a scientific article (either in initial form or popular form) is a second order user. The secondary user is the end user, the consumer or the public. From an evaluation standpoint, the KVC succeeds by providing positive outcomes to the secondary users, persons who do not directly participate in the production or shaping of the knowledge or its support structure. This does not mean that “ordinary citizens” are excluded from the KVC. If an individual benefits from cancer drug, the individual is a consumer, not a member of the KVC. But if the individual also works to change public policy for research on cancer or concerning the use of knowledge from cancer research, the person is both a consumer and a member of the KVC.

The main existing concept that can be compared with a KVC is the scientific discipline. Table 2 presents comparison of both notions along a series of dimensions pointing out the main characteristics of each concept for each dimension.

	Knowledge Value Collective	Scientific Discipline
Inhabitants	Scientists, technicians, entrepreneurs, inventors, manufacturers, activists, funding agents (among others)	Scientists
Knowledge Goals	Heterogeneous and sometimes incompatible	Homogeneous and generally compatible
Norm Consensus	Low	High
Barriers to Entry	Low	High
Social Control	Low	Usually High
Boundaries	(with other KVCs): Poorly demarcated, highly permeable	(with other disciplines): Somewhat demarcated, somewhat permeable
Communication Patterns	Fragmented and concentrated	Formal: comprehensive and highly dispersed; Informal: segmented and concentrated.
Evaluative Mechanisms	Highly diverse and use-specific	Often institutionalized (e.g. peer review)

Table 2: Comparing Knowledge Value Collectives and Scientific Disciplines

The KVC differs from a traditional scientific discipline in several ways including: (1) the inclusion of persons who seek to develop knowledge uses extrinsic to science; (2) the inclusion of multiple and cross-cutting evaluative standards; (3) greater normative diversity; (4) fragmented and less encompassing communications networks; (5) greater fluidity of members and lesser ability to re-create itself by transmitting embodied knowledge and norms from one generation to the next. But the most important difference between a KVC and a discipline or field is the important roles played by people who are not scientists.

The pursuit of knowledge is constitutive of both KVCs and scientific disciplines to the point that in both cases the content of the knowledge has a bearing on the identity and boundaries of both. Knowledge about magnetism and chemical bonds puts those studying each in different disciplines in a similar way as the applications of Nuclear Magnetic Resonance and the development of superconducting materials puts those working on them or using them in different KVCs. However, the binding effect of knowledge pursuits works differently in each case. Fundamental knowledge of the phenomena in the field is always the touchstone of a scientific discipline even when, in practice, its members carry out a variety of activities that do not directly contribute to that objective. The center of the field will be occupied by those who are contributing new knowledge of a fundamental sort. This is not the case in a KVC where the "hot" topic can vary greatly in the sort of knowledge that is at issue. At one point it can be the characteristics of a new material, then the new manipulating possibilities offered by a new experimental technique, then the emergence of new applications for a well known phenomenon, and so on. This also makes the profiles of its central actors different at different times, from academic scientists, to program managers, to industrialists and marketeers.

As a result, KVCs are much less stable over time as their focus and composition shift. Scientific disciplines, on the other hand, do not tend to disappear once established as long as they can justify their social organization as the correlate of a "piece of the world." As a result, as members of disciplines, scientists tend to be more conscious of the boundaries between them even though much of their work may challenge them. KVCs, on the other hand, overlap most of the time because of the multiplicity of uses that are relevant to their members. The density of uses around the main focus is what makes them visible rather than the limits at the periphery.

Most important, an understanding of scientific disciplines tells us relatively little about the processes by which science produces outcomes, but a deep understanding of the KVC tells us nearly everything.

E. KVC Dynamics

Detailing the many and diverse dynamics of a KVC is beyond the scope of this monograph (see Bozeman and Rogers, 2002, for more detail), but a typical dynamic (multiple entry points are possible) begins with the individual scientist plying her internal capacity, augmented by social capital gained from association with the KVC, on a knowledge application (use) set by the prevailing state of knowledge and resources within the KVC as well as her own imagination and skill. In working with extant knowledge, the individual creates new information by developing a new use (extension, technological application, etc.) for extant knowledge. The new information is presented in some manner (research article submission, technological device, new research process) to the user community, the KVC. The KVC may, essentially, ignore or invalidate the new information bringing the knowledge creation process to a (perhaps temporary) dead end. Or the KVC can validate the new information and, when used, transform the information into knowledge value, thereby perpetuating knowledge development or creation. In the later case, use by the KVC, the KVC itself is transformed as a result of an advance in its available knowledge (technology, know-how). Likewise, the process is transformative for the individual who, by her knowledge creation efforts, necessarily increments not only the KVC's reservoir of S&T human capital but her own as well.

F. Evaluating Knowledge Value Collectives

In evaluating a KVC one provides an answer to the question "What is the likelihood that science (i.e. a given KVC) can produce a set of desired social outcomes?"

The actual users of information products, or KVC outputs, are the ones who, in practice, ascribe value. One evaluative issue pertains to the quality of the KVC, its capacity to produce, the other to the outcomes it has produced. These can be detected either in the compilation of uses indirectly observed (e.g. citations), direct testimony (e.g. interview data), or, most important and not-quite-so-obvious, examining the health, vitality and fecundity of the KVC. Presumably, the characteristics of the KVC will be related to its success in "marketing" its outputs and get users to find them valuable. Since the quest for the latter evidence is much less standard than approaches to documenting use, we concentrate on the evaluation of the KVC rather than the equally important task of documenting use.

Knowledge users are the proper evaluators. The churn model eschews any normative framework for costing out the de facto evaluations arising from individuals' discrete choices of knowledge for use in scientific, technical, and production enterprise. Science-in-practice does not take scientific claims in isolation, contrast them with an abstract set of principles in a normative framework and decide to keep them or reject them depending on whether or not they pass the test. It is the success of "packages" of statements and experimental arrangements signaled by their adoption by other researchers that endows the quality knowledge outputs. Nevertheless, if one is reluctant to assess discrete products (or uses), there remains the broader possibility of assessing the capacity of the KVC to produce uses. A KVC capable of producing uses (and able to "translate" others' interests in terms of its own results) is one superior to a KVC not producing uses or producing few uses or producing non-repetitive, unique, or dead-end uses.

C. KVC Dimensions

Three interrelated dimensions capture the *effectiveness of a KVC*. These three dimensions are not just descriptors of KVC's because they capture something more than the structure; they reflect either use or capacity to generate uses for scientific and technical information. These dimensions include: *Growth*, *Fecundity*, and S&T *Human Capital*.

Growth

If a KVC's growth is stunted, so is its potential for producing new uses and establishing new translations. Naturally, measures of growth must take into account the developmental level of a KVC: different growth rates should be expected from emergent configurations than stable ones. After initial identification of a KVC (starting with clues about the nature of "emergent configurations"), a host of growth indicators are of interest. Among other factors, one must examine absolute growth, rates of growth and magnitudes of growth; each is important and likely to capture important information about the KVC.

The nature of "growing" requires some further attention. Above we noted that networks may be initially identified by connections among first order users of scientific and technical information. But once a connection is identified how does it "count" toward growth? Growth is measured in terms of both uses and users. Users are generally easier to measure because small gradations in difference of use cannot be validly measured. But fewer difficulties are posed by identifying users and, here a new concept, "principal uses." A principle use is simply the users' response to the question "what was the principal use to which you put the scientific and technical information you reported having used?" In most instances a direct response from the user is the preferred method of determining principal use (though indirect observations may provide useful for convergent validation). This is not because a user/creator of information is necessarily aware of all the content of all uses. But for purposes of KVC identification and analysis we are not interested in ambient information or the decoupled information employed by user/creators.

Thus, "use" defines KVC "growing" and each use is a connection. There are two kinds of uses as well: those the KVC makes of others' information, therefore attributing value to someone else's work; and those others make of the KVC's information output, therefore attributing value to its work. The ability to do both is important for a KVC: it creates value by making others' work successful when it integrates into its own; and it provides the raw matter for others to create value when they pick up the KVC's information products.

These connections-via-use are more powerful (at least for the evaluator) than those uncovered in communication or citation networks analysis because connections, knowledge, use, and value creation are inextricably intertwined. The social activities of use form a *value nexus*, putting scientific and technical information to use creates knowledge, value and, at the same time, growth in the KVC. The KVC stagnates with decreases in use and, as source-aware use ceases, so does the KVC. Its life cycle depends entirely upon use. The first sort of use (not production) brings it into being, both sorts of uses sustain it and the existence of both is coterminous with growth, cessation of either one sort of use brings its demise.[i]

With slight adjustments in growth measures one captures completely different meaning. If we measure the *size* (absolute numbers of users and principal uses) of a KVC we can determine the *magnitude* of domain (i.e. 50 uses. If we measure the *first differences in growth* over a given period we can determine "base anchored" changes of magnitude (from 50 uses to 100 uses). If we measure *rate of change in growth* (a 150% growth rate over two years) we capture a "base free" proliferation. Each of these is important and tells us something different, interesting, and germane to the evaluation of KVC's. Drawing on these simple measures we can evaluate KVC's as:

1. Low Incidence-High Incidence: they produce more or less principle uses.
2. Expanding-Contracting: by looking at first difference we can determine whether a KVC is getting smaller or larger and we can determine the magnitude in terms of numbers of uses.
3. Rapid Growth-Slow Growth: by looking at rates of change we can determine the pace of uses, ultimately, perhaps shedding light on KVC life cycles (not unlike diffusion curves).
4. Diversifying-Simplifying: by looking at the variety of uses it makes of others' information products versus the relative variety of its own products used by others. Strictly speaking this would not be a measure of growth of the KVC itself but it would indicate its ability to create value out of many sorts of inputs and the ability to provide diverse sources for others to create value. There are four possible classes of KVCs according to this measure: a) simple input to simple input: a simple transformer; b) diverse input to diverse output: a rich transformer; c) simple input to multiple output: a multiplier; d) multiple input to simple output: a filter.

Fecundity

Related to growth, we can evaluate a KVC's *fecundity*, its ability to generate use. In part, fecundity is simply a matter of the growth of the network (since growth and use are definitionally dependent). But fecundity is the power to generate uses rather than the uses themselves. Possibly, fecundity is not directly observable, but good indirect measures can be obtained:

(a) *Longevity*: the ability of a KVC to sustain itself over a long period of time, maintaining a high rate of new principle uses.

(b) *Reach*: the KVC has greater reach if its problem domain is greater in scope (e.g. Callon, 1997, p. 27). A KVC which generates uses in highly diverse and not easily connected scientific problems, disciplines, technologies is said to have great "reach."

(c) *Generative Power*: the KVC which has the ability to spawn new KVC's (i.e. user groups which, while stimulated by the problem domain of the focal KVC, detach themselves and attack new problems enabled by work in the initial KVC). While it is not an easy matter to measure pre-

cisely just when a new KVC has emerged from an old one, this seems at least a possible task and certainly a rewarding one.

S&T Human Capital

An obtained assumption implicit in the foregoing, but which we have not yet stated explicitly, is that knowledge embodied in human beings is of a higher order than disembodied knowledge contained in formal sources (e.g. technological devices, scientific papers). The reasoning is simple: information in formal sources is static and can be reconfigured only by human use and extensions. Knowledge embodied in humans is dynamic and subject to constant and immediate extensions and refinements with no intermediary-imposed lags (e.g. markets, publication delays). Human knowledge capital is, in any event, the source of all formalized knowledge and, thus, the terra firma of knowledge evaluators.

S&T human capital is the sum total of scientific, technical, and social knowledge and skills embodied in a particular individual. It is the unique set of resources that the individual brings to his or her own work and to collaborative efforts. Since the production of scientific knowledge is by definition social, many of the skills are more social or political than cognitive. Thus, knowledge of how to manage a team of junior researchers, post-docs and graduate students is part of S&T human capital. Knowledge of the expertise of other scientists (and their degree of willingness to share it) is part of S&T human capital. An increasingly important aspect of S&T human capital is knowledge of the workings of the funding institutions that may provide resources for one's work. Let us emphasize that none of this discounts the more traditional aspects of individual scientists' talents, such as the ability to conduct computer simulations of geological fracture patterns or the ability to draw from knowledge of surface chemistry to predict chemical reactions in new ceramic materials. The S&T human capital model recognizes that in modern science being scientifically brilliant is only necessary, not sufficient. In most fields, a brilliant scientist who cannot recruit, work with, or communicate with colleagues or who cannot attract resources or manage them once obtained, is not a heroic figure but a tenure casualty or one or another variety of underachiever. Moreover, even in the more focused concern of traditional human capital — pay levels as surrogates for performance — we argue that this broader concept is useful. While the variance in income among Ph.D. holders is less than for the general population, much variance remains to be explained and formal credentials (since there are usually none beyond the Ph.D.) and additional formal education cannot provide much help in the explanation.

The S&T human capital framework assumes:

1. Science, technology, innovation, and the commercial and social value produced by these activities depends upon the conjoining of equipment, material resources (including funding), organizational and institutional arrangements for work, and the unique S&T human capital embodied in individuals.

2. While the production function of groups is not purely an additive function of the S&T human capital and attendant non-unique elements (e.g. equipment), it closely resembles an additive function. (The "missing ingredient" in such aggregation is the salubriousness of the fit of the elements to the production objectives at hand.)

3. Most important, the S&T human capital model of effectiveness is: enhancing the ability of R&D groups and collectives to produce knowledge. Thus, the object of evaluation is best viewed in terms of capacity, not discrete product.

S&T human capital can be examined at any level of analysis, including the individual, the project, or the organization, but it can also be considered in connection with a knowledge value collective. The key issue in the latter focus is: what are the S&T human capital endowments contributing to the KVC (and, implicitly, are they adequate for the social goals expectations that have been established for the KVC)? Figure Five provides a simple model showing the relation of the KVC to S&T human capital for a given project-based team of scientists. The model indicates that a given scientist or engineer has a given level of S&T human capital at time t, and participation in scientific projects and, more generally, scientific networks and broad knowledge value collectives, generally enhance S&T human capital not only by increasing skill-based endowments but also social capital through science-based and science-relevant networks (e.g. industry users, funding agents).

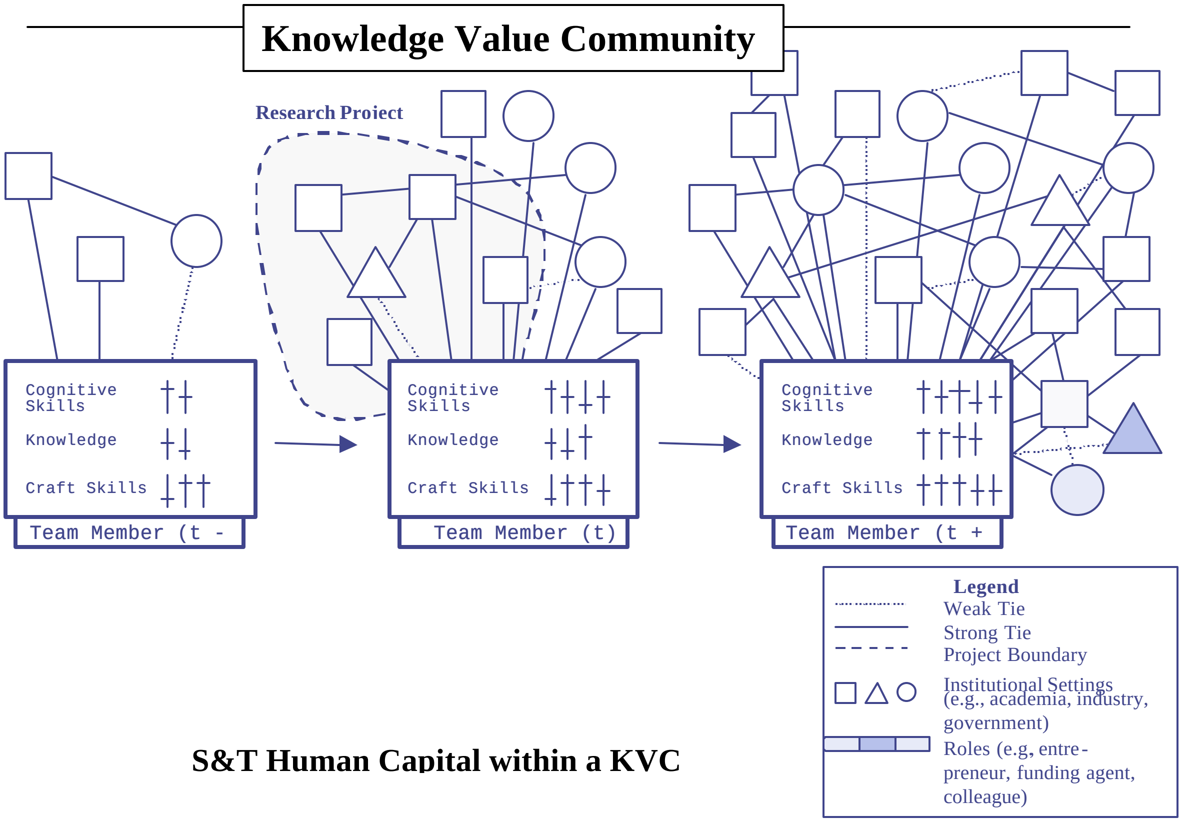


Figure Five: S&T Human Capital and Network Ties within a Knowledge Value Collective

Thus, a key question for all KVC's is the extent to which they engender the building and flow of human knowledge capital. One implication of S&T human capital is that teaching, mentoring, skill development, and "educational products" are not a by-product for evaluators, they are the core. The production of breakthrough (i.e. multiple use) scientific papers is the benchmark of a previously successful KVC; the production of abundant human knowledge capital is evidence of the capacity to produce future, not easily imagined knowledge breakthroughs. R&D value mapping — or most any approach to evaluation — is well served by focusing on human knowledge capital as a core evaluation criterion.

Capacity, Social Outcomes and the KVC

The Case for Capacity. Public Value Mapping focuses on both the social outcomes of the KVC and the qualities of the KVC itself. Each of these is important. If the KVC has limited ability (i.e. collective S&T human capital) to produce desired outcomes, that is important to know if one is to provide public value expectations related to production of social goods. A nation's ability to use science to achieve social goals is a capacity questions, not strictly an outcome question.

Even before Crane's (1972) pioneering work, most students of the social aspects of science and technology understood that knowledge rarely flows according to the organizational and institutional charts set forth by policy-makers and bureaucrats. A "federal laboratory" is an extremely rich admixture of resources and people (some "inside" the organization, some "outside") brought together to address scientific and technical problems. The list of persons on the lab roster tells us little about the work and the connections among the workers. Likewise, a single NSF or NIH small science awardee provides a poor evaluation focus. The money provided to the grant recipient provides the opportunity for her to create new information but it also funds graduate students (with effects quite significant and possibly distantly realized), provides equipment that others will share. One of those students who participates in a "failed project" may learn a technical craft that will enable her twenty years later to produce new, fecund information that will give rise to multiple and widespread use.

Naturally, evaluation clients' patience wears thin waiting the twenty years for the agency-funded graduate student to produce the next great thing. But it is the very "event" focus of R&D evaluation that poses problems. It is not the "event" or the "article" or the "technology" or even the "market" that is the foremost concern, it is the capacity to produce these things and that capacity is embodied in knowledge value collectives. It is here our evaluation tools must be plied. Institutions are important, but they are important because they affect communities. Institutions, programs, and projects exist in the mind of bureaucrats and policy-makers and can be shuffled easily enough. Knowledge value collectives exist as human interactions with information. They are not shuffled so easily. It is easier to say "decommission the federal laboratories" or to wave a wand and say "this university is now in the research park business" than it is to conceptualize and support the KVC focusing on techniques for extracting and using genetic material from the drysophyla. But the most important policy lesson to remember when undertaking the daunting task of organizational and institutional designs is to not let them get in the way.

The Case for Outcomes

The problem with focusing only with capacity is that there is not a perfect correspondence between capacity and outcome. Related, capacity to produce tells nothing about who benefits from the outcomes of science or even who has access to the benefits. While market frameworks and economic theory do not invariably suggest that "more is better," certainly the fact that the entire discipline of economics is premised on allocation of scarce goods often supports the ideology of material abundance. Until relatively recently, few have challenged the traditional rationale for massive public sector investment in science and technology: the expectation (based on the linear model of innovation) that these investments will increase nations' economic growth and productivity. But in nations, such as the U.S., where there is existing abundance (albeit maldistributed abundance [Rose, 1992]), we might do well to consider Daniel Boorstein's argument that prosperity is better measured by needs met than by goods and services produced. Even so prominent a figure in the science policy establishment as the late Congressman George Brown, long time leader on the House Science and Technology Committee has begun to question the technology-economic growth-social benefit model:

> (W)e justify more growth because it is supposedly the most efficient way to spread economic opportunity and social well being. I am suggesting

> that this reasoning is simplistic and often specious. When economic growth does not lead to greater public good, we are not inclined to blame dumb objects — technologies. Rather, we blame imperfections in the market system....We often argue, in effect, that we must change reality so that it conforms more closely to a theoretical construction: the perfect marketplace. This is like saying that we need to change the second law of thermodynamics so that it conforms more closely to perpetual motion. Suppose that we viewed economic markets as an imperfect artifact of human culture, instead of vice-versa? (Brown, 1993, p. 414)

There is a well known innovation bias, not only in the literature about science and technology, but even in many cultures. One reason to focus as much on outcomes as capacity is to ensure that the *right* outcomes occur rather than simply ensuring that the invention factories (to use Edison's term) are efficient and productive. As Congressman Brown (1993) noted, "Technologies themselves have a profound impact on our daily lives, but it is fruitless to speculate on whether that impact is predominantly positive, negative, or neutral."

Assessing the outcomes from science is an entirely different and more challenging problem than assessing scientific productivity. Nevertheless, the public value mapping method is an attempt, albeit primitive, to do just that, to determine if the outcomes from science correspond to the legitimated social goals we have set for it.

IV. Public Value Mapping Methods: The Fundamentals

To reiterate, the objective in developing a Public Value Mapping of science outcomes is to create a valid, practical, outcomes-based approach to assessing large-scale science and research policy initiatives, an assessment focus that transcends the project or program level and examines broad social impacts. What is missing from research evaluation and, almost by definition, from program evaluation is an evaluation method that moves beyond the program level to focus much more broadly on the ability of sets of program, agencies, and even sets of agencies to achieve broader social impact missions. To some extent, this was the dream more than thirty years ago of early social indicators researchers and theorists. But the primary objective of social indicators was not so much linkage of government action to outcomes reflected in social indices as it was the development of social indicators useful for social monitoring and the planning of government programs. This is a subtle difference in some ways, but one with profound implications for method and approach.

The PVM analytical approach differs from most program evaluations in that rather than starting with the program activity or even the program objective, the method will begin with the mission [whether or not a formal mission statement is available] and work back to determine the relationship of government actions to that mission. In the PVM initial stages, government agencies' and programs' formal missions, strategic and policy statements serve as surrogate public value indicators (subsequent results may help re-frame the definition and indicators of public value).

The theoretical pre-suppositions of PVM are presented above, but there are also some core methodological and operational assumptions. The fundamental assumptions and operational procedures of PVM can be summarized as follows (these are elaborated subsequently).

Assumptions

- PVM can be either prospective (analyzing planned or projected research activities), "formative" (analyzing such activities as they are occurring), or "summative" (evaluating activities and their impacts after they have occurred).

- PVM focuses at the level of the “knowledge value collective” and examines the social impacts it engenders. An important methodological aspect, then, is to provide a specific, operational definition identifying the KVC of interest. The KVC includes the scientists contributing knowledge to the target issue of interest (e.g. genetic engineering of crops, breast cancer prevention and treatment) but also institutional and stakeholders shaping social impacts.

- In focusing on the KVC, PVM NEED VERB both the capacity of the KVC (its potential to create new knowledge and applications) and the outcomes it engenders. Analysis focuses, then, on the KVC’s scientific and technical human capital, guiding policies, its network linkages and institutional configurations, the resources in the environment and available to the KVC and, in general, the ability to deploy successfully the knowledge produced by the scientists and technicians working in the KVC.

- PVM seeks to take into account the highest order impacts of activities (i.e. broad social aggregates) and, thus, ultimately ties evaluation to social indices and social indicators.

- PVM is multi-level in its analysis, seeking to show linkages among particular program activities of an agency or institution, activities of other agencies or institutions, relationships — either intended or not — among various institutional actors and their activities.

- PVM assumes that all programmatic and research activities entail opportunity costs and, generally, the goals and outcomes achieved are necessarily at the expense of other possible goals and outcomes that could be achieved by alternative uses of those resources.

- PVM is guided by a “public value model of science outcomes” rather than a market-based or market failure model. PVM explicitly rejects evaluation and assessment based on commodification of research values and outcomes. Market prices are viewed as weak partial indicators of the social value of research and research outcomes. Even as a partial indicator, market value is considered in terms of not only magnitude but also distribution and equity criteria.

- Since market value is eschewed in PVM and since generally agreed upon public values are rarely available, PVM anchors its outcomes values in a wide range of criteria derived from diverse sources including:[1] official, legitimated statements of policy goals; [2] goals implicit in poorly articulated policy statements; [3] government agencies’ goal statements in strategic plans and GPRA documents; and [4] values derived from public budget documents. While value expressions of politically legitimated policy actors are examined first, public values may be supplemented with statements of value in opinion polls; official policy statements by relevant NGOs; policy statements of public interest groups.

- Research techniques employed in PVM depend upon the needs and possibilities afforded by the context of its application. The only technical approach used in each application of PVM is the case study method. In-depth case study and historical analysis is always an element of PVM. Accompanying research techniques will be chosen in terms of their relevance to the particular PVM science and outcomes domain. (Examples of some of the research techniques that may be employed include: Survey research, polling, and questionnaires; focus groups; analysis of aggregate data about outputs and impacts; expert opinion, including structured expert opinion such as Delphi technique, contingent value analysis; patent and citation analysis.)

- PVM is designed explicitly to be prescriptive and uses its data and results to provide information about program planning, design and implementation.

Summary of Procedures

Public Value Mapping is a flexible, context-specific method, not an "off-the-shelf" approach. Not only are the procedures likely to be different from case to case, but the steps will differ. Thus, the operations procedures identified below (and elaborated subsequently in this paper) are best viewed as an archetype.

Step 1: Provisionally, identify research and social outcomes domain and the KVC associated with the domain.

In conventional program evaluation, the task is often simplified by the fact that the client provides a definition of the domain of interest. But PVM explicitly rejects a unitary or single perspective definition of the research domain. As a problem-driven approach, PVM considers research and programmatic activities from the perspective of the knowledge value community; the role of any particular research program or agency is considered in relation to that broader, multi-actor context.

The PVM can begin by identifying either a body of research activity (e.g. research on breast cancer) or a set of social problems that research addresses (e.g. reduction of breast cancer). But both the social problems and the research activity directed to it should be identified, provisionally, in the first step. (This identification is provisional because subsequent learning may show that the definition of the research or the problem domain should be expanded or contracted from initial expectations.)

Step 2: Identify measurable public values

In most cases of PVM of public research programs, the mission and goal statements of the sponsoring entities should prove satisfactory statements of public value. Even in those cases where mission statements are sufficiently precise to use as public values, it will be useful to also examine all relevant public value statements, including authorizing statutes, other statutes, GPRA documents, official press releases, speeches by official actors, budget statements and rationales. Most important, it will rarely suffice to confine to a single agency or organization the search for public value statements. Many fields of research are not "owned" by just one government agency and, thus, identifying public values will also entail understanding actors involved in funding, performing and setting priorities for research.

In most instances, these procedures, when applied exhaustively, will provide a suitable list of potentially measurable public values. In those rare instances where this process yields public value statements that are too imprecise or too general, it may be necessary to supplement authoritative government statements of public value with public value statements that do not have the imprimatur of official actors. These may include statements of public interest groups, NGOs, lobbying groups, public opinion polls and expert testimony. Each of these sources is problematic and, if at all possible, should supplement officially vetted policy statements rather than supplant them.

Step 3: Sort values.

In most cases, the procedures of Step 2 will yield an impressive list of potentially measurable public values. In Step 3, values should be sorted in such a manner as to

1. Identify the relative importance of the values to the study, including,
2. Determine a values hierarchy (or at least determine that the values are not in hierarchical relation,

Caution: Problems of Value Assessment

Public managers in federal agencies have for several years grappled with the requirements of the Government Performance and Results Act of 1993, a management initiative requiring a strategic plan, goals and objectives statements and means of providing evidence that goals have been achieved. This is certainly not the first time that federal officials have found themselves in a thicket of ends and means. Earlier approaches, such as management by objectives, planning programming budgeting systems, and zero based budgeting, all had similar requirements for clearly expressed goals, identification of linkages among goals, and specification of the actions and programmatic activities contemplated as a means to achieve goals.

It is almost always the case that efforts to implement such rational management and decision-making plans seem logical, sensible, and straightforward right up to the point that one starts the undertaking. But in the middle of such efforts managers and those to whom they report often begin to wonder why something that seems easy enough —specifying goals and relating means and ends — turns out to be so challenging and, later, why the products of such exercises so often prove disappointing. There are actually several important reasons why such rational management approaches so often fail and many of these have been widely chronicled in the public administration literature: the power of political expediency, the costs of information and analysis, the difficulties of thinking about the long term while serving in an environment dominated by short term outcomes, and the inertia of large bureaucracies, including the ability to wait out the latest management reform. But there is another problem that has received a bit less attention, one that is relevant to the task of developing public value criteria. The sorting out of values is a remarkably difficult analytical task. When we impose requirements that values be considered together, especially in their hierarchical relationship, the task is often too difficult or at least to resource-intensive.

We cannot avoid some considerable conceptual and terminological analysis in route to the question "how to sort public values" and the place to start is with value itself. The most important distinction, and a particularly troublesome one, is between *instrumental values* and *prime values*. Prime values are those that are ends in themselves, that once achieved represent an end state of preference. In the social sciences, the distinction between prime and instrumental values is generally recognized but many different terms have been used for the distinction, some with slight differences of meaning. Dahl and Lindblom (1953) refer to prime and instrumental values, but others (see Van Dyke, 1962 for an overview) use the terms proximate and remote, immediate and ultimate, and even independent and dependent (Perry, 1954) (in a usage opposite to what one would expect from dependent and independent variables).

The primary characteristic of a prime value is that it is a thing valued for itself, fully contained, whereas an instrumental value is valued for its ability to achieve other values (which may or may not themselves be prime values). Van Dyke (1962) speaks of instrumental values as conditions and prime values as consequences. This helps clarify only so long as one remembers that instrumental values are not the only consequences affecting the realization of prime values and that the assumptions we make about the conditions required for the achievement of instrumental values often prove wrong.

In the manner in which the terms instrumental and prime value are used here, each of the following statements of relation is true and each makes analysis of values complex and difficult:

1. For any individual, a value can, at the same time, be both an instrumental value and a prime value.
2. Prime and instrumental values may affect one another in reciprocal relations.
3. Instrumental values have both hypothesized consequence and (if obtained) actual consequence; these two types of consequence may or may not correspond to one another and may or may not affect the prime value (or remaining instrumental values).
4. For any individual, a value may at one point in time be an instrumental value and at another point in time a prime value.
5. Prime values may contradict one another and instrumental values may contradict one another.
6. No value is inherently a prime value; ascription of value is a matter of individual, dynamic preferences, generally based on partial information about the desired state represented by the value.

Let us begin with the last point since it so often gives rise to confusion. It is certainly the case that we can identify values that most people hold. Most people prefer life to death, good health to bad, and food to hunger. But the facts that people commit suicide, chose to act in ways clearly contrary to good health, and go on hunger strikes from various political or personal reasons suggest that there is in no meaningful sense a prime value held universally by all persons at all times. But so long as one recognizes that there are no values invariantly prime, point (5) needs not wreak havoc. Clearly, the only way there could be an invariantly prime value would be if there were only *one* prime value. There is always the possibility that what was formally a prime value (e.g. avoiding hunger) will be called into service or even reversed in an attempt to achieve what is at any particular point in time viewed as a more important prime value (e.g. making a statement of political protest). This implies, of course, points (1,2) above.

Point (3) above is especially critical for analysis of values. From the standpoint of empirical social science, the fact that prime values are not intersubjectively held or experienced is vexing and limits the ability of the social scientists to inform. But the role of the social scientists is virtually unbound with respect to instrumental values. *All instrumental values can be viewed as causal hypotheses that are, in principle, subject to empirical tests.* Consider the following statement: “The agency’s mission is to contribute to the quality of life and economic security of individuals who are unemployed or under-employed due to their having few skills valued in the marketplace. After identifying persons eligible for the program and recruiting them to the program, the program objective is to provide 100 hours of formal training in heating, ventilation and air conditioning mechanics and repair and to place the program participants in internships that will prepare them for full-time employment HVAC jobs.” In this case it is reasonable to assume that the agency mission is a reasonable equivalent of a prime value- providing jobs that increase economic security and quality of life seems a good “end point” or consumption point value, a value worth achieving for the benefits if confers. The program objectives — identifying and recruiting personnel, providing training and apprenticeships — seem to be instrumental value. True, there are some people who will likely derive aesthetic satisfaction from mastery of HVAC, even if it does not lead to an improvement in their employment status. Similarly, the recruiting of persons for the program may have some consumption point value for both the agency and the program recipients — the agency is more likely to thrive and sustain itself if it has program participants and the recruits may enjoy the social interactions and acquaintances provided by the program. But it is certainly arguable that the program objectives are close equivalents to instrumental values.

3. Identify linkages among values, including means-ends relationships.
4. Assess the extent to which values are measurable,
5. Begin preliminary operationalization of values.

In all likelihood, these values will not be inter-related in obvious ways and there can be no mechanistic approach to sorting values. It is possible to suggest a few heuristics, however. In most instances, values should be given priority according to their expansiveness. The highest level values (at least) should be prime values rather than instrumental values. This is one of the more difficult aspects of PVM and a short digression (see insert below) shows why.

Step 4

PVM analyzes (maps) the causal logic relating goals statements (any of the above) to science and research activities, impacts and outcomes, both measured and hypothesized. When possible, this analysis begins with the causal logic articulated by responsible officials. The causal logics, explicit or implicit, that are the basis of science and research activities are then considered in relation to various plausible alternative hypotheses and alternative causal logics invented by the analyst.

1. The search for evidence of impacts and social outcomes begins only after compiling a set of goals, identification of research activities and outputs, including relationships of institutional actors to one another and to their environment, and an understanding of causal logics, including plausible alternative hypotheses and alternative causal logics. In each case, the causal maps should be traced to the highest order impacts, as reflected in possible changes in social indicators. The search for impacts should be guided by the causal logic maps (both official and alternative) and hypotheses developed.
2. After gathering data to test hypotheses about causal logics and outcomes, appropriate analysis (selected depending upon specific analytical techniques used), is employed to test hypotheses and, at the same time, measure impacts and outcomes. Results of analysis focus on interrelationships among the causal logic, the environmental context and measured impacts and outcomes.
3. PVM formal analysis concludes with a linkage of impact and outcome measures back to aggregate social indicators or other appropriately broad-based, trans-institutional, trans-research program measures of social well being.
4. PVM concludes with recommendations focusing on possible changes (in research or program activity, causal logic, implementation) that seem likely to lead to improved social outcomes.

V. Conclusion

If one is interested in measuring public value, it certainly seems possible to measure both the prime and the instrumental values and, most important, to test the de facto causal claims presented in the agency policy statements. To a large extent, this is much like what serious program evaluators have been doing for years. What is different about the analysis of public value mapping as compared to the evaluation of programs? Despite many similarities, the analysis of public value differs in several important ways. Perhaps the most important difference is that PVM is concerned about the prime value rather than the contribution of particular instrumental values (or of particular agency programs) to the prime value. This implies that analysis begins with aggregate social indicators, focused at an appropriate level of analysis (but almost always at a level higher than suggested by the case of an agency's recruited clientele); that the critical issue is change in the observed state of the prime value(s), and that the focus of causation is much broader that standard program evaluation, examining the program activities of any relevant actors as well as the factors (which may not relate to systematic program activity) either increasing or decreasing the level of attainment of the prime value. The public value mapping question, then, is this: "given that a prime value has been achieved to a given extent, what factors cause aggregate change in the measured prime value?" In this manner, PVM involves causal testing of propositions about impacts on prime values and charts changes in the achievement of prime values, but does not either start with a specific set of programmatic objectives nor does it focus exclusively on them. PVM is, then, an analysis of the ecology of value achievement and a dynamic and continuing approach to monitoring both changes in outcomes and the ecology of value achievement. This implies, of course, that instrumental values (e.g. recruiting persons to participate in programs) receive no more attention than any of a host of factors (e.g. general economic conditions, resources applied to achieving the prime value) hypothesized as affecting the prime value. An upshot of this approach is that PVM will be less useful than program evaluation for suggesting specific changes in program delivery and more useful for understanding broad social problems and factors contributing to their mitigation and, thus, should prove especially useful for program design and agenda setting.

PVM draws from disparate theoretical stands and prescribes methodological and operational approaches that are fluid, drawn together only by a foundation in historical analysis and case studies, a pragmatism in use of quantitative methods and a commitment to causal analysis ("mapping") of the chain from knowledge production and use to social impact. The proof of the approach will be in accompanying applications, including the breast cancer research case provided in a companion monograph. PVM is, at this stage, a "pilot" assessment method, subject to revision as the various applications determine what is and is not possible with respect to data availability, analytical strategies, and time required for the intensive analysis suggested by the approach.

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1 The term “Big Science” is used in a number of quite different ways (Institute of Medicine, 2002), but we refer to those instances in which multiple scientific institutions are harnessed to address large-scale social goals, generally goals legitimated by public policy initiatives. This is at odds with the most familiar usage (de Solla Price, 1977).

2 The experience of the U.S. is quite different from Canada, which has for more than a decade mandated formal evaluations of public-funded R&D, and to the United Kingdom and many other European nations that have led the way in developing research evaluation and in its use in policy-making.

i The emphasis on use which we contrast with production does not deny the importance of the information products a KVC creates. We state the emphasis with this contrast to drive the point home that the focus on outcomes that prevails in research evaluation takes them in isolation from the use to which they are put and the use of other information products they reflect. However, it is the ability to generate these uses that we argue must be sustained and the emphasis on the products obscures the transactional nature of this process.