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Public Value Mapping and Science Policy Evaluation

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Abstract Here we present the framework of a new approach to assessing the capacity of research programs to achieve social goals. Research evaluation has made great strides in addressing questions of scientific and economic impacts. It has largely avoided, however, a more important challenge: assessing (prospectively or retrospectively) the impacts of a given research endeavor on the non-scientific, non-economic goals—what we here term "public values"—that often are the core public rationale for the endeavor. Research programs are typically justified in terms of their capacity to achieve public values, and that articulation of public values is pervasive in science policy-making. We outline the elements of a case-based approach to "public value mapping" of science policy, with a particular focus on developing useful criteria and methods for assessing "public value failure," with an intent to provide an alternative to "market failure" thinking that has been so powerful in science policy-making. So long as research evaluation avoids the problem of public values, science policy decision makers will have little help from social science in making choices among competing paths to desired social outcomes.

Keywords Public values · Research choice · Research evaluation · Science policy · Market failure

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Introduction

Science policy did not become the focus of serious intellectual inquiry until the early 1960s. Previously, debates raged in both England and the United States about the extent to which science could be directed toward societal aims, but such disagreements (exemplified in England by the 1930s debates between J.D. Bernal and Michael Polanyi [e.g. see Freeman 1992], and, in the U.S. by the policy debates that pitted Vannevar Bush against Harley Kilgore shortly after World War II [e.g. Kevles 1995]) were little informed by robust theory and even less by data. In large part, *Minerva*, first published in 1962, was created to help fill this intellectual and research vacuum. “Improved understanding of the relations between government and systematic and disciplined inquiry in science and scholarship was taken as the subject matter of *Minerva*,” wrote its first editor, Edward Shils (1968, p. xiv). Shils’ explicit hope was that such understanding would “make scientific and academic policy more reasonable and realistic” (p. xiv).

From the beginning, the central problem in science policy was recognized by workers in the field as the problem of choice. In a world of finite resources, how should policy-makers choose among the many competing scientific disciplines, projects, and programs in making public investments? *Minerva* published three early, seminal papers on this problem (Polanyi 1962; Weinberg 1963, and Toulmin 1964), and many others that contributed to setting the terms of the problem. As Toulmin (1964) noted, the choice problem was both “difficult and inescapable.” Difficult not only because the problem itself was poorly specified, but also “because we are sheerly ignorant about many of the relevant factors and relationships” between scientific advance and societal “repercussion” (p. 343).

Toulmin’s discussion of the choice problem remains particularly apt for two reasons. First, he identified the two important poles that still represent the organizing dichotomy of work in the subsequent four-plus decades: the “economist’s view, according to which science is basically deserving of support because it is the handmaid of industrial growth; and a scientists view, representing technology as a kind of scientific roulette in which those who plunge deepest tend to win the biggest prize” (p. 348). Second, he recognized that the problem of choice was significantly a “chalk-and-cheese” problem, where diverse activities categorized as science (much as chalk and cheese might both be categorized as “crumbly white-ish materials”) were in fact constituted by a multitude of activities that were in many ways incommensurable, so that, for example, “the choice between particle physics and cancer research becomes a decision whether to allocate more funds (a) to the patronage of the intellect or (b) to improving the nation’s health. *This is not a technical choice, but a political one*” (p. 357).

Toulmin’s identification of science policy’s economic and scientific poles, and his recognition of the chalk-and-cheese problem, help to explain why, despite three decades’ progress in the ability to conceptualize, measure, and evaluate research impacts, a gaping hole remains in research evaluation methods and technique: the ability to evaluate the *social and public value impacts* of research. Indeed, such impacts have been defined out of the problem as at once irrelevant (they are not encompassed in the science-economy dimension) and inaccessible (they simply add to the already intractable problem of incommensurability of choices).

Thus, professional researchers have developed powerful economic tools to measure economic impacts of research, sophisticated bibliometric tools to measure the impacts of research outputs on scientific fields and the course of science and technology, and improved peer review techniques for assessing projects, programs and proposals. But there has been remarkably little progress in the ability to measure directly, systematically, and validly the impacts of research on social change. Many scientists (e.g. Ziman 1968) have extolled the communal and cultural value of scientific knowledge. However, without rejecting compelling arguments for the intrinsic value of research in intellectual, cultural and aesthetic terms (Fischer 1997), most policy-makers and citizens seem to agree that the chief purpose for public funding of research is to improve the quality of life (Johnson 1965). And most scientists justify it as such.

As Toulmin (1964) and his colleagues well understood, the critical problem of choice is not that the chalk-and-cheese problem is at heart a political one, but that we have no satisfactory analytical tools for characterizing the social impacts of chalk *or* of cheese—for understanding, that is, causal impact and magnitude of effects of research activities on social change. This gap is not surprising when one considers the difficulty of the task and the adolescent stage in the development of research evaluation. Yet, part of the problem is self-imposed: if science policy research in the past 40 years had focused as energetically on the problem of social values and social impacts as it did on assessing scientific and economic impacts, we might have made considerably more progress on resolving the problem of choice. This counterfactual suggestion is not mere philosophizing, as we hope to demonstrate by the case studies that follow this paper. Not only are the diverse public values that are invariably deployed to justify scientific choices ascertainable, so are the relations among such values, and, to an extent, the capacity to advance them. With this in mind, and to provide a theoretical and methodological framework for the subsequent case studies, in this paper we will consider: (1) why new approaches and alternatives to research evaluation are needed and how they relate to extant approaches; (2) special difficulties or challenges of developing such approaches; and (3) a specific methodological framework that can be employed, which we here term "public value mapping of science outcomes." Importantly, the work described in this paper and the cases that follow are supported by the U.S. National Science Foundation program on the 'Science of Science and Innovation Policy,' (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501084) a program that in turn responds to the observation by a former U.S. presidential science advisor that "the nascent field of the social science of science policy needs to grow up, and quickly" (Marburger, 2005).

Growing Up Quickly: Bringing Public Values to Science Policy Processes

U.S. science policy since World War II has to a large extent centered on three interrelated clusters of values. The value cluster we label "Scientific Productivity" includes concerns about the quality and quantity of U.S. research output, perceived or measured world leadership in science, human resources issues, including not only the "pipeline" but also the capacity of scientific fields, and, of course, funding issues, usually framed as "why we need more money for science." These values occupy Toulmin's "science" pole. The second value cluster, corresponding to Toulmin's economic pole, is a continual and pervasive concern with economic productivity, which includes concerns about innovation, technological advance, economic growth and, in some instances, an implication that economic benefits, widely shared, will advance social goals and quality of life. A third value cluster, "Defense and National Security," includes concerns with weapons superiority, developing non-weapons technology to support the military, and generally, using science and technology to enhance military strength expressed regionally and globally.

Obviously there are other core values associated with publicly funded science, and it is certainly the case that U.S. science policy continues to add new values and attendant missions. The 1970s witnessed the emergence of values clusters pertaining to energy and environment. The vast expansion in the 1980s of the National Institutes of Health was rationalized largely on the basis of improved health and well-being. Yet, for all four broad areas of research—military, energy, environment, and health—the public values served by such priorities have been significantly subsumed by the demand for scientific excellence in the pursuit of enhanced economic productivity (e.g. Sarewitz 1996). (For example, the military rationale has been largely subsumed by the core values of science [i.e. via the crucial role of the U.S. Department of Defense in building academic science programs, e.g., see Leslie 1993] and economic growth [e.g. "dual use technology" and "spin-offs," e.g. see Ruttan 2006].) The result is that the breadth of values *expressed* in U.S. science policy is significantly wider than the breadth of values directly pursued or assessed. In particular, and as documented in each of our case studies, even where broader public and social values are expressed in science policy development, they are often subverted, reinterpreted, and subjugated to the science-economy axis. The result is a winnowing of values brought to science policy and, overall, a decrement in *public* values. Thus, our goal in this paper is both to discuss why public values are so easily deflected in science policy, and also to suggest an approach to tracking public values and monitoring and evaluating their influence on science policy.

Before discussing the reasons why we feel it is especially difficult to infuse and maintain public values in science policy, we consider the meaning of "public values." We use this definition:

> "A society's "public values" are those providing normative consensus about (1) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled; (2) the obligations of citizens to society, the state and one another; (3) and the principles on which governments and policies should be based" (Bozeman 2007: 37).

Our focus on public values requires at present no more precise definition, but we note these implications of the above definition: (1) public values are not static and immutable, there is no "natural law" or "natural rights" meaning to our concept of public value; (2) economic values may in some instances qualify as public values; (3) in some instances and for some policy controversies, there may be insufficient consensus to identify public values (however, this is rare); (4) public values may conflict (e.g. liberty and security, privacy and transparency); (5) public values may or may not be interdependent.

We aim to increase the public values component of science policy, essentially expanding science policies' dominant value sets, by making it possible to consider diverse values using methods and criteria comparable to those already widely accepted and used for scientific and economic values. This goal immediately raises a practical concern: Where can public values be found? A nation's more fundamental laws and, if there is one, its constitution, provide good starting points for identifying public values, though public laws and public policies are best viewed as reflecting and expressing public values rather than establishing them. If policies do not necessarily tap the roots of public values, they often can be taken as surrogates. For example, laws or policies may be justified (e.g. in legislative language or agency strategic plans) on the basis of a public value such as "improvements in public health and longevity," or "decreased infant deaths," or "cleaner air." One can expect disagreements on the need for and desirability of additional increments in any of these values, but few would find the public values themselves to be objectionable.

Another obvious and time-tested approach to tapping citizens' values is by public opinion survey.[1] There is abundant information about such issues as trust in government, division of responsibility between federal and state governments, political ideology, and responsiveness of government (see Nye 1997). Careful study of general views and values of citizens—studies performed apart from any specific decision—may be useful for making specific choices, such as whether government or the private sector should manage the state prison. This suggestion is not unlike the widespread practice, used especially in local governance, and, recently, in conjunction with new internet and telecommunications technology (e.g. Budd and Connaway 1997), of citizen polling (e.g. van Houten and Hatry 1987). It is simply polling citizens about their most fundamental values.

Third, some recent studies (Bozeman and Sarewitz 2005; Feeney and Bozeman 2007) seeking to apply public values criteria have employed a posited model (Bozeman 2001), one that has the value of being explicit and of providing criteria not dissimilar to those from ubiquitously applied market failure models. We discuss the posited model below. Finally, we note that public policy statements can in many instances be taken as de facto public values and that a valuable activity of policy analysts is to track the evolution of those values as policies evolve from ideas premised on diverse and deep values to practical, front-line policies that may be far removed from the values summoned initially to articulate or defend policy ideas. A recent study has applied public value mapping in just this manner to the field of nanoscale science and engineering (Fisher et al. 2010).

[1] A distinction should be made between public opinion and public values: Whereas public opinion is highly volatile, both in its concerns and its directions, public values are much more stable. New public values may enter and old ones may exit but generally only after great social change and the passing of generations.

In short, the answer to the question "Where can public values be found?" is that they are located in a great many places: formal scholarly literature, cultural artifacts and traditions, government documents, even some opinion polls (ones receiving valid and representative responses to questions about core values). Jorgensen and Bozeman (2007) sought to develop an inventory of public values from such sources, as well as from the public documents and literature on public values, public interest and governance. Civil societies are necessarily permeated by public values since it is these that provide much of the structure of civil societies to begin with. And, crucially, specific public values are selected to justify science policy and other government actions. A greater problem than identifying public values is understanding them in some analytically useful form.

The Need for Public Values in Science Policy

Many major science policy initiatives are premised on values one might take to be "public values." It is not difficult to find values statements supporting research for environmental protection or health, for example. Why do we feel there is an under-emphasis in public values in science policy? In the first place, public values are more likely to contain as their content the end state outcomes ultimately important to most people. For example, few care about economic growth per se. Economic growth often is taken as a surrogate for well being or even happiness, but in fact economic growth is by most accounts an instrumental value, a way of achieving broader public values such as family health, leisure, safety, clean air, education and job attainment and career satisfaction. But why *begin* with surrogate values? Is it not more sensible to premise policies on the outcomes they should achieve rather than the instruments presumed (perhaps erroneously) to enable those outcomes?

Second, public science is supported by tax dollars, under a tax system that is designed (however inadequately) to be progressive and promote equity. One reason to infuse public values in science policy is that they are by definition broader values and by implication ones more likely to affect all or most citizens. Yet, it is by no means clear that the dominant values of scientific excellence and economic productivity are sufficient to account for the broad range of values that the public hopes to gain from science. Most obviously, even the idea of the linear model of science policy, science leading to technology leading to goods and services leading to economic growth, has been thoroughly repudiated by economists of innovation (e.g. Rosenberg 1982). But even if it were true, the idea that all will benefit from the economic growth ends of science and technology, even though widely asserted, has little plausibility (e.g. Woodhouse and Sarewitz 2007).

Third, one must be vigilant about public values in science policy because they are so easily subverted. This point is subtler than the previous two. We can say that science policy values, and indeed all values expressed in all major policies, are dynamic, and that they evolve in stages, albeit not always in a straightforward fashion and not always sequentially. In most instances, stages include (1) agenda-setting, (2) policy design(s), (3) policy choice, (4) policy implementation and (usually but not always), (5) policy assessment or even systematic evaluation.

Values are important at every stage, but they are volatile. In some cases values change as a result of learning, in some cases they atrophy for lack of advocacy, and in still others they fall under the weight of new values infused by self-interested parties (i.e. politics).

Different types of values are privileged at different stages (Baumgartner and Jones 1991). In particular, broad public and social values fare well at the very outset when policy rhetoric and ideals are articulated and advocates seek support for policies. At that stage, before policy-makers and other parties have settled to the business of making difficult choices and having to mount rationales or even evidence for those choices, it is easy enough to speak broadly about public values. Once the dust settles, and policy options are winnowed, public values are often shunted to the background as advocates and disputants begin to negotiate, usually on a narrower basis. The public values remain as justifications for policies, sometimes even tacked on as rhetorical cover to sub-optimal or patched together policies that accommodate a great many conflicting values, including many private ones or ones advanced by narrow coalitions.

But public values usually are not advanced during choice processes, for three related reasons. First, science values and economic values are available as accepted and dominant surrogates for all other values. Second, public values are supported by no coherent set of conceptual tools to aid in choice. Third, and in contrast, many such tools are available for science and economic values. In particular, the market failure model is easily available, widely known, anchored in theory assumptions consonant with much of U.S. policy-making, and, thus, it often plays a role in framing choices and in the policy choices themselves. The market failure model also directly links the core science value of knowledge creation to the economic rationale via the discredited yet ever-present linear model. Availability is everything and there is no corresponding model of public values or public interest to compete with market failure and similar decision models based loosely on microeconomics.

After their initial use as rationales or rhetorical devices, public values tend to stay at the rear throughout the remainder of the R&D policy process until such a time as public officials or other interested parties began to question whether the policy has had desired results. In some such instances public values make a return appearance, but usually not for long. The reason they are again set to the side is that one quickly finds that both the analytical tools at evaluators' disposal usually have little to do with public values—but mesh quite well with Economic Productivity or Scientific Productivity values sets. One sees this process at work in each of the case studies that follow this introductory paper. For example, the application of nanotechnology to cancer has been justified for its potential to contribute to equitable health outcomes, but in the end is assessed in terms of the broader economic goals of nanotechnology innovation (Slade, this issue); research on hurricane tracking is supported for its capacity to improve preparedness but continues to displace other, perhaps more vital, lines of research on the basis of claims of scientific excellence and opportunity (Maricle, this issue).

To reiterate our most fundamental point, while there are many reasons to expect that public values will often be displaced in science policy, there are two key problems that can be addressed and remediated. First, the lack of adequate conceptual apparatuses to compete against market failure and other economics-based models means that advocates for public values have limited analytical support. We have begun to address this issue elsewhere (Bozeman 2001; Bozeman and Sarewitz 2005) by providing a "public values failure" model that is a rough equivalent of the market failure model, and which is adopted in all the following case studies. Second, approaches to evaluating science and technology outcomes have been dominated by techniques and methods anchored either in microeconomics (e.g. cost benefit analysis), supporting the economic productivity value set, or bibliometrics (e.g. citation analysis, co-citation networks) supporting the academic productivity value set. As we will show, however, a competing approach rooted in public value assessment is not merely practicable, but revealing.

Bearing in mind this relationship between public values infusion in science policy and the difficulty of bringing public values to bear in evaluation, we consider in the next section the evolution of research evaluation and, particularly, reasons why public values have been conspicuously absent in both formal evaluations and indicators-based assessments. We focus particularly on the economics origins of research evaluation because most research evaluation remains centered on economics and because bibliometric approaches tend to be less general in their purview and less often in competition with public values concerns.

Economics Bases of Research Evaluation

For present purposes, we mean by "research evaluation" any systematic, data based (including qualitative data) analysis that seeks as its objective to determine or to forecast the social or economic impacts of research and attendant technical activity.[2] (For a more detailed but similar definition, see Luukkonen-Gronow 2007). In post hoc research evaluation, the focus is generally on some set of discrete scientific or technological outputs such as publications, patents or some other expression of intellectual property. Importantly, formal research evaluation always involves some such discrete commodity, either singly or aggregated. Rarely does it begin explicitly with the goals, objectives, or values of the program and then trace back to various outputs and impacts.

Formal research evaluation is a recent invention and its origins tell us much about why it remains dominated by economic analysis and economic values, with public values having made little headway. As late as the 1980s, research evaluation was a field with few practitioners, mostly focused on economic evaluation of industrial firms' internal rate of return.[3] Whereas the Canadian

[2] By "research assessment," not our focus in this paper, we mean an investigation with similar objectives but not necessarily including data and perhaps premised on indicators but with no formal analysis.

[3] During the history of modern science and technology policy and research evaluation, the most prominent approach to assessment has been peer review. While recognizing that peer review is crucially important, the present study focuses on systematic and potentially quantitative or mixed-method approaches and, thus, does not discuss peer review approaches to research evaluation. Similarly, this paper does not deal with the many and increasingly useful bibliometic approaches to research evaluation.

government[4] and some European nations[5] had begun systematic evaluation of publicly funded research, in the United States and many other nations, evaluation of public research impacts was not a field at all, but rather an agglomeration of fragmented, largely isolated works, many unpublished.

To understand the roots of research evaluation one can consider the state-of-the-art as reported in one the earliest reviews focusing specifically on studies of the evaluation of publicly funded research. Salasin, Hattery and Ramsay's *The Evaluation of Federal Research Programs* (1980) stated 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 generally or research evaluation specifically, most of them based in industry. The resulting monograph cited 49 papers, including exactly one journal article (Rubenstein 1976) and one book (Andrews 1979) focusing explicitly on systematic evaluation of *government-sponsored* research. The monograph identified four problems endemic to evaluating government research 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.

Since then, studies and methods of R&D evaluation have greatly proliferated (for an overview of approaches and methods for research evaluation, see Bozeman and Melkers 1993; OECD 1997 and OECD, in press). But most of the problems identified nearly three decades ago in the Salasin, Hattery and Ramsay's pioneering monograph still exist, particularly the problems associated with a focus on discrete R&D outputs. This is especially inimical to public-values-based research evaluations inasmuch as discrete outputs in most cases can hardly begin to provide an adequate gauge for the social change sought from research programs.

Economics Bases for Research Impacts Evaluation

Economic assessments of research and technology generally fall into two basic categories, one of which is most relevant to practical research evaluation. Less relevant to practical evaluation, but influential to broad science policy decision making and rationalization—not to mention the core rhetoric of national politics—are aggregate-level production function analyses (e.g. Solow 1957), typically focusing on the contribution of technology to national or regional economic growth. More useful for research evaluation are those economic studies seeking social rates of return (e.g. Jones and Williams 1998), that is, approaches that use indicators of marginal economic benefit as a surrogate for estimating the social utility of research and technology. The implication is that wealth can be used to obtain socially

[4] For a history of government mandated research evaluation in Canada, including research evaluation, see Auditor General (1993). For a history of research evaluation activities in Canada, see Barbarie (1993).

[5] Several publications provide synoptic reviews of the history and methods of research evaluation in European nations; see, for example, Luukkonen (2002); Callon, Laredo and Mustar (1997).

desirable outcomes and, thus, increments in wealth can be taken as indicators of social benefit. Among social rate of return approaches, benefit-cost analysis has been most common and most prominent in project and program-level evaluations of research (see, for example, Link 1996a; 1996b; Ruegg 1996; Audretsch et al. 2002).

Aside from the possibility that one may not wish to assume that economic benefits, measured in monetary terms, fully express or stand in for public values, there is also the issue that very few such studies even begin to consider equity issues in the distribution of benefits. This is not because the evaluators do not recognize the distributional issues in play in science and technology outcomes, but rather because the methods and techniques employed cannot in most instances accommodate distributional variables (Martens 2009).

Because economics approaches to research evaluation focus on discrete technological outputs such as patents and articles, they are useful for those who wish to aggregate outputs and consider them in connection with, for example, the performance of technology transfer programs and regional commercialization efforts. The utility of these approaches should be obvious even to skeptics. While the benefits of economics-based approaches to evaluation are explored in more detail elsewhere (Link 1996b), we can for present purposes summarize them as follows:

1. Evaluation rooted in neoclassical economics seems to hold forth promise of "harder" more rigorous analysis and, thus, matches well the policy-maker's need for metrics to justify expenditures. Typically, these approaches yield numerical assessments of such factors as increments in patents or job creation or firm partnerships (Kostoff 2001).
2. Whereas most approaches to research evaluation are either atheoretical and exclusively tool-oriented, or based on poorly developed theory, economics approaches can draw from decades of development of relatively strong (for the social sciences) theories of the firm, rational choice and economic growth.
3. While economists recognize that there are values that cannot be well accounted for by monetized units, many have been quite creative in developing quasi-economic techniques based on preference functions and units that mimic rational economic choice (e.g. contingent value analysis [Cummings and Taylor 1999]).
4. Economic development and growth is a driving impetus for policy and politics throughout the world, and as we have emphasized, science and technology policies are strongly rationalized in terms of pursuit of economic growth. It is not surprising that economics-based approaches to research evaluation underpin economics-rationalized science and technology policy.

Despite their many advantages, economics-based approaches to research evaluation have many limitations, especially if one is interested in gauging the impact of research on public values and social change.

1. As already mentioned, most economic approaches to research evaluation focus on the discrete products of research. While this is methodologically sensible, in that it promotes measurement, it also promotes a narrowness of view. For example, if one is interested in the long-range capability to produce innovation, then simply counting the results of discrete products may not provide a good

insight into the health and viability of scientific fields or a nation's innovation systems. If one is interested in the capacity to produce innovation, rather than just the innovation products themselves, then a focus on "scientific and technical human capital"—the integrated social networks and aggregate skills of scientists (Bozeman et al. 2001)—and other, non-economic, approaches to evaluation are required. As well, a focus on particular products and projects works best when there are crisp boundaries (e.g. a single R&D project), while most social objectives do not have easily discernible boundaries and are influenced by myriad causal factors. An approach focused on assessing the capacity to achieve non-economic public values requires methods permitting soft boundaries.

2. Despite efforts to consider implications of future streams of benefit, economics-based evaluations tend to be static. They rarely take into consideration the mutability of the "products" evaluated, much less the changes in the persons and institutions producing them. Thus, an economic analysis of the impacts of a mechanical heart valve innovation would have great difficulty taking into account broad secondary effects such as the implications for a longer-lived population or for equity of health care access, and would also have difficulty tracing the differential impacts of successive generations of the technology.
3. Product-oriented and output-focused 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.
4. Most important and obvious for present purposes, there are just some things that money can't buy: many social benefits and costs of research are not well or even validly accounted for in monetary units. For example, while economics does a good job of *precisely* measuring the value of a human life, the question of whether such measures as life-time earnings capabilities are also *accurate* indicators is utterly laden with values that are non-economic. Indeed, as the subsequent case studies document, research is generally justified on non-monetary values and, thus, the evaluation of research in purely monetary terms amounts to a sort of bait-and-switch, where public policy intent becomes transformed by subjecting it to the available theories and evaluation methods, as if one went to a doctor for a health examination and ended up with an assessment of one's earning potential.

It is this latter limitation, the inadequacy of economics-based approaches for measuring and providing understanding about the social impacts of research, that is our chief concern here. To be sure, economics approaches are not unique in their inadequacy for this task. Currently, no satisfactory method (except, perhaps, case studies that are very context specific and rarely generalizable) has been developed to validly assess the impacts of research on social change.

Social Impacts of Research: Challenges to Theory and Method

A methodological problem in all approaches to research evaluation is that research is often only one factor in determining social outcomes and is rarely the most important one. The science advisor to President Obama has identified a series of "challenges" for U.S. science and technology that include "better [health care] outcomes for all at lower cost," "poverty eradication," "transforming the global energy system," and "reducing risks from biological and nuclear weapons," (Holdren 2009) but of course when research plays any significant role in achieving such desirable social outcomes it is in concert with a great many other social, economic and natural determinants. The outcomes, that is, are highly-overdetermined. In such circumstances, it is virtually impossible to parse out the contribution of research; this is what Toulmin (1964 p. 343) meant when he observed that "we are sheerly ignorant about many of the relevant factors and relationships" connecting science to outcomes. Our ability to trace these links is not much better now than it was in 1964. Whether one employs standard economics-based approaches such as cost-benefit analysis, social indicators monitoring and social accounting, or even in-depth case studies, causal attribution for complex social impacts is always fraught with great difficulty.

A related problem pertains to the "dependent variables." Determining causation is difficult enough, but often the effects are themselves interwoven in ways that are difficult to understand or unravel. Social outcomes occur in clusters. For example, in the case of automobile safety, research has shown that safety innovations such as disk brakes or even seat belt laws can actually result in more accidents as drivers' behavior becomes more risky as a result of technologies providing an increased sense of security (e.g. Adams 2006). Similarly, many of the social and public health gains that have been realized by smoking cessation programs are offset by the fact that reductions of smoking have contributed in some degree to the increase in obesity rates. Our case studies demonstrate these complex and contradictory effects: technology transfer programs may lead both to increased wealth and to greater inequities (Valdivia, this issue); advances in nanotechnology-based cancer treatments appear likely to increase health inequities that are already significant in the U.S. (Slade, this issue). In short, in modeling social outcomes from research one has difficulty not only tracing cause to effect, but also setting boundaries on effects. This is one of the reasons why we have adopted an open, "mapping" approach to evaluating public values. We are not seeking a deterministic model, but rather an approach that can enhance insight, debate, and expectations—and thus improve decision outcomes.

A related complication to developing public values theory in general and public values in science policy in particular is that not all values are public values, and means of demarcating values are hardly clear-cut. Consider this general definition of "value": *"A value is a complex and broad-based assessment of an object or set of objects (where the objects may be concrete, psychological, socially constructed, or a combination of all three) characterized by both cognitive and emotive elements, arrived at after some deliberation, and, because a value is part of the individual's definition of self, it is not easily changed and it has the potential to elicit action"* (adapted from Gaus 1990). Given this not unfamiliar description of value and the previous definition of "public value," it is perhaps apparent that the distance traveled from one to the next is considerable. From the standpoint of empirical social science, the fact that values held by individuals are not agent-neutral provides limits in values analysis. However, if the role of social science is limited with respect to such private values, it is virtually unbounded (though poorly developed) with respect to *public* values, because public values are typically instrumental, or employed instrumentally.

In seeking public values and their application, public value theory (Bozeman 2002; 2007) embraces empirical social science. We begin with the assumption that all instrumental values, public, economic or private, can be viewed as causal hypotheses that are, in principle, subject to empirical tests. From here it becomes possible to seek and even test public values statements found in broadly held articulations of desirable states toward which progress can be assessed ("decreased infant deaths"; "cleaner air"). We are not after prediction or proof, we are after plausibility, which seems to us a desirable, reasonable and achievable expectation for science policy-making (or any policy-making, for that matter). Meyer (this issue) shows, for example, that the internal logic of the climate science policy process in the U.S. is completely incoherent, and for that reason alone can have little capacity to achieve the goals that justify and motivate the program. What makes this analysis possible is the recognition of the public values embedded in the process, and the logical relations (or lack thereof) among these public values.

Getting on With It: A Sober and Humble Rationale for Evaluation of Social Impacts of Research

The foregoing section identifies formidable obstacles to assessing the social impacts of research and, unfortunately, the list above is not exhaustive (for a more detailed discussion of problems in tracing social and public value impacts, see Bozeman 2007). Yet, whether or not fully adequate analytical tools are available, policy-makers will continue to make choices about research funding. These choices will continue to be premised on a causal logic. As we have discussed, and as the cases document in greater detail, in making decisions about investments in research, policy-makers make assumptions about the effects of those investments on such social outcomes as public health, transportation systems, education, and wealth creation. In most instances those choices will, perforce, be based on limited information provided by interested parties. Any evidence that can be brought to bear on those choices, even when fraught with known methodological limitations, is likely an improvement over intuition, habit, rough-hewn ideology, political self-interest, powerful myths about how the world works, and other such biases that so typically guide investments in research aimed at solving social problems. If nothing else, new approaches can contribute to: a) disciplined discussion, healthy skepticism and reflection and b) openness to other, clearer, non-scientific options. It is in that spirit that we began to fashion the approach we refer to as "public value mapping."

Public Value Mapping and Its Lineage

Put simply, public value mapping is an approach to identifying the public value premises of public policy and then tracking their evolution and impacts on policies and, ultimately, social outcomes. The primary rationales for the public value mapping of science (PVM) are that (1) the focus of science policy should be on social goals and public values, and (2) current research evaluation and science policy analysis methods and techniques are not sufficient for analysis of the impacts of research on public values and fundamental social goals.

From the outset, public value mapping, an approach aspiring to practical application, has been rooted in public value theory. While we do not have space or great need to go into the details of public value theory, it is perhaps useful to provide a modest introduction.

A PVM taproot is new theoretical thinking about the value of knowledge and its assessment (see Bozeman 2007 for a summary). To a large extent, recent work on the value of knowledge is a response to limitations of economic theory in understanding knowledge value (e.g. Bozeman and Rogers 2002). Economists have never made much headway valuing scientific knowledge (see Machlup 1962). Scientific knowledge, in economic terms, is generally considered a pure public good, and thus, an example of pricing inefficiency. In the world of public finance economics, theory loses its power in instances where markets do not work in straightforward fashion and where efficient pricing is impossible. However, it is generally in these realms that public values and, for that matter, governments and policies operate. Thus, stretching economic theory to the breaking point, rather than developing theories of public and social value, seems a poor route forward.

Philosopher Elizabeth Anderson (1993) presents an especially interesting analysis of economic value and value theory as it pertains to economics. Anderson’s position, one that would perhaps seem radical to many social scientists, is that economic values are inherently monistic. Because of the fundamental structure of assumptions built into economic values, they cannot accommodate pluralistic approaches to values. To put it another way, an analysis valuing exchanges, commodities, and services on the basis of market standards pre-empts simultaneous, comparable reference to other standards (see Marmolo 1999; Anderson 1993). These assertions have direct implications for models of innovation and the impacts of scientific and technical knowledge.

In addition to philosophy of values, public value theory draws from the field of public administration (e.g. Van Wart 1998; Jorgensen, 1996; Van Deth and Scarbrough 1995; Kirlin 1996; Bozeman 2007). In public administration, a useful theory is a theory in practice (Adams, 1992). Perhaps for that reason, much theory that underpins analysis of public values is anchored in various aspects of pragmatism (e.g. Shields 1996; Garrison 2000; Bozeman 2007) and especially developing communitarian and procedural approaches suitable for the identification of and support of public values. Public administration literature (e.g. Van Wart 1998; Jorgensen 1996; Van Deth and Scarbrough 1995; Kirlin 1996) has begun to move from philosophical discussion of the public interest to a concern with identifying aspects of publicness or public values. Case studies (e.g. Jorgensen and Bozeman 2002) focus on how public values are infused (or not) in public decisions. To a large extent, the cases following this paper have that intent: to demonstrate and assess the extent of public values in public policies and to trace their roles and impacts.

Public value mapping can best be thought of as an analytical confederation. It is not a unified method nor does it aspire to closure. Indeed, it is not a method, per se.

It is better viewed as a loose set of heuristics for developing analyses of public values. Public value mapping begins with a set of core assumptions but these are not inviolable. Table 1 (Bozeman 2003) provides these core assumptions. The cases following this paper, diverse as they are, strive to conform to these assumptions.

Table 1 Core Assumptions of Public Value Mapping

1. PVM is 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. It seeks to take into account the highest order impacts of activities (i.e. broad social aggregates) and, thus, focuses on social indices and social indicators.
3. It 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. Related,
4. PVM is concerned with understanding the environmental context for research and related programmatic activities, locating the activities and their institutional actors in terms of other actors in the environment, the constraints, opportunities and resources presented in the environment.
5. Research in any field by any method is embedded in a social context; in PVM analysis of the social context of the research (i.e. characteristics of research performers, their attributes and social relations) is a part of the analysis.
6. 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.
7. Since market value is eschewed in PVM and since social values are not interpersonally transmissible, 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; [4] aggregated statements of value represented in opinion polls; [5] official policy statements by government actors; [6] official policy statements by relevant NGOs.
8. 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.
9. PVM is not an analytical technique or even a set of analytical techniques, but a model that includes a guiding theoretical framework (public value theory), a set of assumptions and procedures. Research techniques employed in PVM depend upon the needs and possibilities afforded by the context of its application. The only technical approach used in all applications of PVM is the case study method.
10. 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.
11. PVM 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.
12. PVM concludes with analysis and recommendations focusing on possible changes (in research or program activity, causal logic, implementation) that seem likely to lead to improved social outcomes.

Public Value Mapping Criteria Model

Just as important as the core assumptions of PVM are the analytical heuristics it brings to bear. Among these, we have found the public value mapping criteria model is useful for structuring analysis and assessment. These PVM criteria begin with a set of general criteria developed for judging public values failure (Bozeman 2002; Bozeman and Sarewitz 2005), but there is no claim that the criteria are canonical or exhaustive. Indeed, as presented in several of the cases that follow, the PVM approach encourages the further articulation of the criteria developed previously as well as the stipulation and justification of new criteria.

Public value criteria serve as heuristics for deliberation. Discussion and argumentation about public values and their measurement proves less troubling in those instances when there is a clear starting point, when one has at his or her disposal public value *criteria.* Even when debates rage about choices of public value, concepts of public value, and the relevance of public values to particular states-of-affairs, one has hope of making headway if there are recognized public value criteria structuring arguments. Perhaps more important, the lack of public values criteria explains in part why economic frameworks such as market failure have often held sway, even in cases where they seem poorly adapted to the problem at hand.

Initial criteria for judging public values failure emerged in large measure as a conceptual parallel to traditional market failure criteria. While these public value criteria were set as companions to market failure criteria, initially they were posited rather than derived empirically. However, the criteria were subsequently submitted to test in various case studies, including cases pertaining to genetic modification (Bozeman 2002; 2007), public health issues in influenza vaccine (Feeney and Bozeman 2007), and nano-scale science (Fisher et al. 2010), among others.

Public value failure is not a conceptual alternative to market failure. Rather, *public values failure occurs when neither the market nor public sector provides goods and services required to achieve public values.* This implies that public values can be realized (or can fail) under any set of market conditions. The chief point of PVM criteria is to expand the discussion of public policy and management by assuming that government (and market organizations as well) need be more than a means of ensuring market successes and technical efficiency in pricing structures. A fundamental assumption of the PVM model is that, contrary to current political dogma and academic thinking, market failure actually tells us little about whether government should “intervene.” With PVM, the key policy question becomes: “Whether or not the market is efficient is there nonetheless a failure to provide an essential public value?” The PVM criteria model provides multiple lenses for viewing this question. It is not a precise decision making tool (a la benefit-cost analysis), but a framework to (1) promote deliberation about public value (and its relation to economic value) and (2) provide guideposts for analysis and evaluation, within the context of public value mapping.

The PVM criteria themselves (Table 2, adapted from Bozeman 2007 and Bozeman and Sarewitz 2005) are not, then, actual public values but, rather, a set of diagnostics applicable to questions of science policy (see Bozeman and Sarewitz 2005)

Table 2 Public failure and public policy: a general diagnostic model

Public Failure Criterion	Failure Definition	Science Policy Example
Mechanisms for values articulation and aggregation	Political processes and social cohesion insufficient to ensure effective communication and processing of public values	Peer review, the favored means of making decisions of individual-level projects, is appropriated for decisions about huge scientific programs, resulting in the displacement of social goals for more easily resolved technical goals
Imperfect monopolies	Private provision of goods and services permitted even though Government monopoly deemed in the public interest	When public authorities abrogate their responsibility for overseeing public safety in clinical trials for medical research, there is potential for violation of public trust and public value
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	The premature privatization of the Landsat program shows that a scarcity of providers can create a public failure potentially remediable by government action
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 energy R&D, by considering the short term, fails to fully capture the costs of global climate change on future generations
Substitutability vs. conservation of resources	Policies focus on either substitutability or indemnification even in cases when there is no satisfactory substitute	No-net-loss' policies fail to take into account the nonsubstitutability of many natural organisms ranging from wetlands protection to prohibiting the sale of human organs on the open market
Benefit hoarding	Public commodities and services have been captured by individuals or groups, limiting distribution to the population	A prime technical success of genetic engineering, the 'terminator gene,' proves an excellent means of enhancing the efficiency of agricultural markets, potentially to the detriment of millions of subsistence farmers throughout the world

and research evaluation. Since science policy, as is the case with nearly all legitimate public policies, seeks ultimately to produce positive social change, it is subject to many of the same public and social values as other policies and, thus, the same values criteria prove useful. The case studies following this paper each employ the PVM criteria model in their analysis and different aspects are relevant in different cases.

Developing and Applying PVM

While considerable conceptual work has already been undertaken to provide building blocks for public value mapping, efforts thus far have been incremental. The goal of this paper and accompanying cases is to begin to create a viable approach that can generate practical analytical tools and insights about public values in science policy. It is also to inspire others working in the field of science policy research to critique, adopt, transform, and apply public value mapping to what remains the central unresolved challenge of science policy practice: the development of evaluative methods that can help us make progress—theoretical, methodological, and most important, practical—on the problem of choice.

All PVM approaches, included those presented here, begin as case study analyses. Each of the cases strives to implement the following four steps (though they vary in the extent to which each is emphasized). At this point in the development of the model we consider these steps to be the procedural core of PVM:

1. A search for "public values" pertaining to the case: We have discussed several approaches to identifying public values, including (a) surrogate public values (government mission statements, strategic plans, and broad policies, statutes); (b) distillation of public values from relevant academic literatures; (c) public values as expressed in public opinion polls and public statements.
2. Application of the PVM criteria: Each case study examines the course of public values in light of the criteria presented in the PVM criteria model, using these criteria as a means of assessing possible failures in achieving public values. Not only do analysts apply useful and appropriate PVM criteria, but they are encouraged to identify criteria that do *not* fit their case and to begin to develop *new* PVM criteria that may be useful for their case and may be generalizable to others. There is an explicit expectation that the PVM criteria model will expand and refine its criteria, not to such an extent that highly idiosyncratic criteria will be included but to include criteria that have some potential for use in multiple cases and analyses.
3. Developing value analysis chains: Among the many reasons why public value analysis of science policy has made little headway is that values analysis itself is remarkably underdeveloped. One of the difficulties of values analysis (Gaus 1990) is that analysts sometimes fail to consider interrelationships among values, including such features as values hierarchies, conditional relations among values, logical structures of multiple and related values, and ends-means relations (Braybrooke and Lindblom 1963). One of the key objectives of the

public value mapping is thus to develop the ability to clarify relationships among values, and assess how those relations influence the links between the conduct of research and the pursuit of particular desired outcomes.

4. Graphically display the relations between market failure/success and public values failure/success, using the public values failure grid (Bozeman 2002; Bozeman and Sarewitz 2005). The grid provides a qualitative, synoptic view of the results of the public value mapping, and thus helps with both communication and comparison. (For reasons of space, we do not illustrate the grid here; it can be seen in each of the case studies.)

In addition to adopting these four steps to ensure some intercomparability of both method and result, the cases also (1) perform the traditional case study role of "thick description"; (2) provide a context for the application of a variety of analytical approaches, including logic models and value chain analysis; (3) help determine the extent to which it is possible to distill public values in a satisfactory manner; (4) extend the theories upon which PVM is premised; (5) point the way for further development of analytical tools.

Finally, each case implicitly adopts one or more analytical lenses to guide its development. The analytical lenses can be thought of as essentially master hypotheses about possible determinants of the public value *outcomes* for the cases. We articulate the lenses in terms of the following contextual factors that affect the social impacts of research and science and technology policy.

a. *Characteristics of the knowledge that the research produces*. In some instances knowledge creation processes, innovation, and, ultimately, social impacts are very much governed by inherent characteristics of the science or technology (e.g. "technology push"), for example, conventional chemistry often uses stoichiometric reagents as a basis for creating desired products because they are convenient, economical, and traditional. But they are also wasteful and polluting. In contrast, "green" chemistry, which includes as an explicit public value the reduction of chemical pollution and toxicity, focuses on using catalysts to achieve the same economic and public values as conventional chemistry, but with much less waste (Logar, this issue).
b. *Institutional arrangements and management affecting knowledge production and use*. This lens pertains to the configuration of producers and users of scientific and technical knowledge, the ways in which they interact, their internal and network management. In the case of climate change research, for example, institutional networks developed largely in support of values associated with ensuring high quality science, a situation that has proven very hard to alter despite a growing awareness that the current arrangements are not serving a range of public values that justify the investment in climate science (Meyer, this issue). Slade (this issue) shows that, in research on nanotechnology-based cancer treatments, insufficient attention to questions of diversity and inclusiveness in both basic and clinical research potentially undermines the capacity of the research to reduce health disparities.
c. *Policy and political domains of knowledge production and use*. This analytical lens examines the political, legal, public policy and normative factors that

determine research choices, utilization and impact (e.g. characteristics of intellectual property policy or structures of budgets for research). Valdivia (this issue) shows, for example, that although Congressional debates over technology transfer policy in the early 1980s did indeed show attention to a broad range of public values, the legislative and regulatory processes ended up neglecting such values for a much narrower focus on economic efficiency and wealth creation.

Conclusion

We began this paper with Toulmin's chalk-and-cheese metaphor pertaining to incommensurate activities grouped together under the category "science." His metaphor speaks to specious aggregation, a difficulty that in turn conceals a still greater problem: omission. We may recognize that biochemistry cannot easily be played off against subatomic particle physics, but in its focus on the outputs of science qua science, research evaluation elides the deeper policy question: on what basis can we decide the extent to which *either* is worth doing? In publicly funded science, public values are often displaced, minimized, misrepresented or altogether missing. A common scenario (we hope not the *most* common) is "bait and switch." During the agenda-setting phase of public policy, tax dollars spent on science and research are rationalized in terms of explicit and invariably lofty public values (*everything* is worth doing). After securing a place in the policy agenda, science policies fall prey to the same interest group politics and forces of institutional inertia that characterize most policy domains, often leading to incremental changes in the status quo. Scientists find ways to rationalize just how the research they have always been doing fits perfectly with the new goals and public value rhetoric. We could refer to this as the "phrenology problem": were the government to provide a billion dollars for phrenology research, many scientists would find ways to call themselves phrenologists. Institutions are no less indefatigable in their adaptation. Bureaucratic sinkholes serve as burial ground for public values. By the time research policy plays itself out at the level of individual choice (that is to say, the same scientists conducting science in the same institutional settings in which they have always worked), we can only hope for some remnants of public value. At this point, any public values that may have been prominent at the outset of research policies are likely only to be resurrected to justify the next increment of funding.

This is, of course, a pessimistic view, perhaps even a bit extreme, but generally descriptive of most instances of large-scale policy choice in science, where high minded beginnings translate into claims of progress measured by publications, citations, or patents and justified in terms of "scientific excellence" or contributions to "innovation" or economic growth. One role of evaluation, including research policy evaluation, is to hold feet to the fire. In the cases where the pessimistic scenario described above is also a most accurate one, should we not expect research evaluators to play a role as truthsayers, or if that is too ambitious a term, an alternative voice? By this point, research evaluation has developed serious methods and techniques and even if the term "science of science policy" remains more aspiration than reality, evaluation has made great strides. However, those strides have been in three directions, none leading directly to the amelioration of what we may refer to, with apologies to Toulmin, as the chalk-cheese-choice problem. The oldest form of systematic evaluation, peer review, while changed, remains recognizable to peer reviewers of decades ago. Would we expect peer reviewers, when “peer” is defined in terms of technical expertise, to provide insight into bait and switch or the displacement of public values? Greater strides have been made in the application of economics to research evaluation. While there is some potential for adapting microeconomics and cost-benefit analysis to research evaluation, most any economist will readily declare that the discipline does very well with questions of efficiency and is generally unsuited to questions of equity. To the extent that public values in science questions are efficiency questions, then economics has much to contribute. Perhaps the greatest strides in research evaluation have been in the area of bibliometrics. In less than thirty years, the field has gone from citation counts to all manner of sophisticated analyses of academic productivity and collaboration networks. That is to say, bibliometrics can tell us much about the input side of science and quite a bit about the output side, but, as we have said, the impact focus remains narrow: productivity and collaboration.

The research presented in these next papers is not as venerable as peer review, not as precise as economics-based evaluation, and not as ruthlessly objective as bibliometrics. However, the papers do seek, through detailed exploration of cases using the PVM lens we have outlined here, to directly address the science policy elephant-in-the-room: the public value of publicly funded science. We recognize that these are tentative steps, but at least they are looking in the right direction, rather than under the proverbial lamp post that shines its bright light on what we can already do—assess scientific excellence and economic productivity—while leaving the rest in abject obscurity. We believe the papers represent progress toward addressing the chalk-cheese-choice problem but, even if they do not, we hope they will stimulate others to give more thought to the formidable challenge of expanding the domain of exploration to address and assess what is surely the core claim of science policy: that science outcomes should serve and advance public values.

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