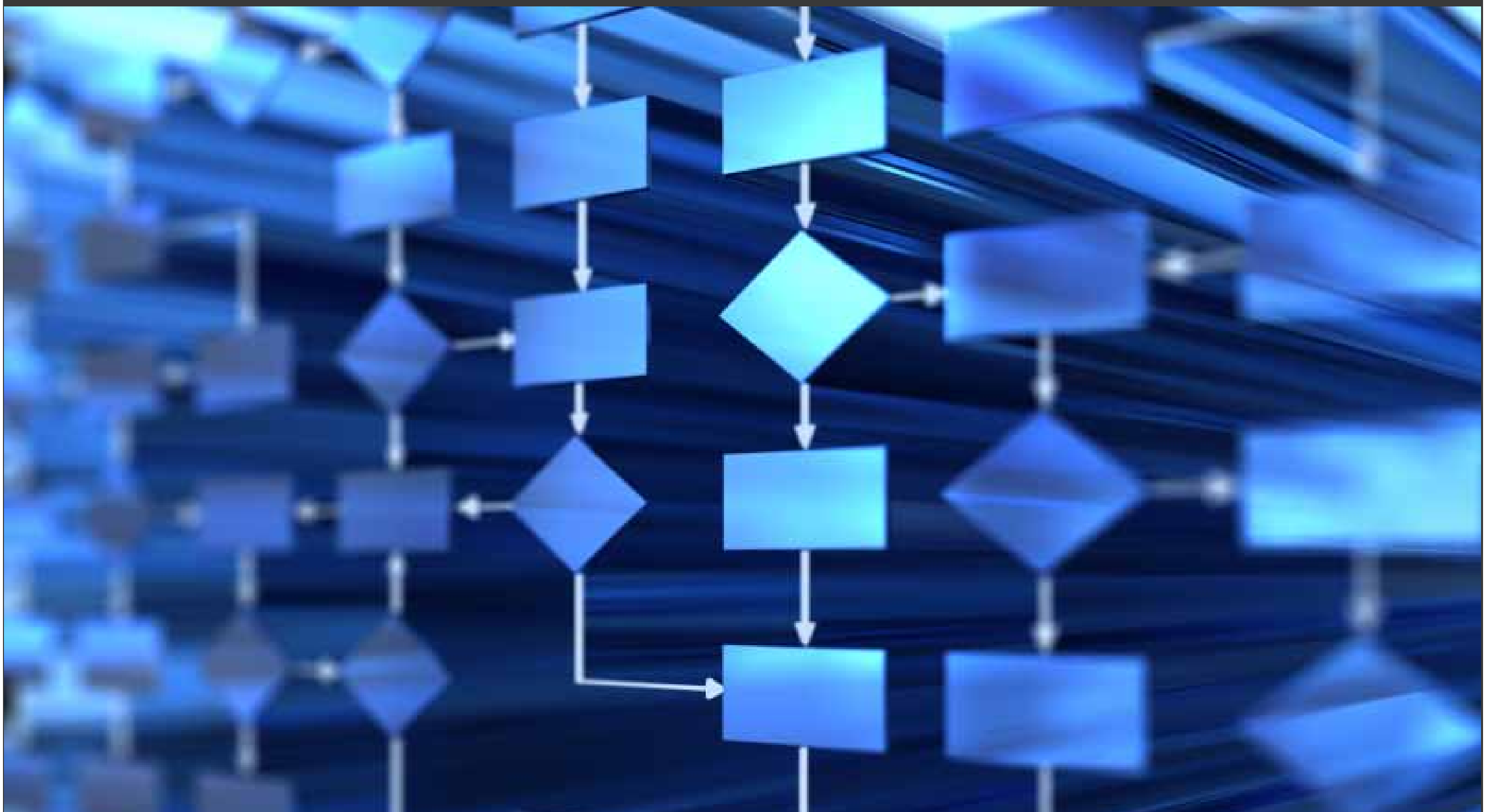
RSD FOR RSSIP WORKSHOP

RECONCILING THE SUPPLY OF AND DEMAND FOR RESEARCH IN THE SCIENCE OF SCIENCE AND INNOVATION POLICY

12-14 MAY 2009 | OSLO, NORWAY



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WORKSHOP ON RECONCILING SUPPLY AND DEMAND FOR RESEARCH IN THE SCIENCE OF SCIENCE AND INNOVATION POLICY

AGENDA

TUESDAY 12 MAY

9:00	Meet in Hotel lobby to walk to Norwegian Research Council
9:30	Welcome, Overview Merle Jacob Roger Pielke, Jr.
9:45	5 minute introductions
12:00	Lunch
13:00	**SESSION I: WHAT DO POLICY MAKERS WANT?** **(* a maximum of 10 minutes for comments)** ***Moderator: Shep Ryen, Arizona State Univ., Consortium for Science, Policy & Outcomes*** Jack Marburger, former Presidential Science Advisor (2001-2009) Michael Rodemeyer, University of Virginia Stian Nygaard, Centre for Innovation, Research and Competence in the Learning Economy Representative, Ministry of Education and Research
15:00	Coffee
15:30	**SESSION II: WHAT DO RESEARCHERS CONTRIBUTE?** **(* a maximum of 10 minutes for comments)** ***Moderator: Ingrid Weie Ytreland, Centre for Technology, Innovation and Culture*** Claire McInerney, Rutgers University Kai Larsen, University of Colorado Barry Bozeman, University of Georgia Per Koch, Norwegian Research Council
17:30	Wrap up Dinner on Own

WEDNESDAY 13 MAY

9:00	**SESSION III: ORGANIZATIONS AT THE INTERFACE** **(* a maximum of 10 minutes for comments)** ***Moderator: Merle Jacob, Centre for Technology, Innovation and Culture, Univ. of Oslo*** Deborah Stine, Congressional Research Service Steve Rayner, Oxford Institute for Science, Innovation, and Society Magnus Gulbrandsen, NIFU-STEP
10:30	Coffee

11:00 **SESSION IV: RESEARCH ON RESEARCH**

(* a maximum of 10 minutes for comments)

Moderator: Monica Gaughan, University of Georgia

J. Britt Holbrook, University of North Texas

Eva Lövbrand, Linköping University

Roger Strand, University of Bergen

Goran Sundquist, Centre for Technology, Innovation and Culture, Univ. of Oslo

12:30 Lunch

13:30 **SESSION V: CASE I, INNOVATION AND SCIENCE POLICY**

(* a maximum of 10 minutes for comments)

Moderator: Eli Moen, BI Norwegian School of Management

Nathaniel Logar, Arizona State Univ., Consortium for Science, Policy & Outcomes

Shobita Parthasarathy, University of Michigan

Shali Mohleji, University of Colorado

Merle Jacob, Centre for Technology, Innovation and Culture, University of Oslo

15:15 Coffee

15:45 **SESSION VI: CASE II, ENERGY/CLIMATE POLICY**

(* a maximum of 10 minutes for comments)

Moderator: Roger Pielke, Jr., University of Colorado

Suraje Dessai, University of Exeter

Elizabeth McNie, Purdue University

Marianne Ryghaug, Norwegian University of Science and Technology

17:30 Wrap up

Group Dinner at Lofoten Fiskerestaurant, on Aker Brygge

Stranden 75 (Ph: 22 83 08 08)

THURSDAY 14 MAY

9:00 **SUMMARY REFLECTIVE PERSPECTIVES AND DISCUSSION (10 minutes each)**

Barry Bozeman, University of Georgia

Steve Rayner, James Martin Institute, Saïd Business School

Per Koch, Norwegian Research Council

10:15 Coffee

10:45 **PLENARY DISCUSSION**

Moderators: Merle Jacob and Roger Pielke, Jr.

How well do science policy researchers meet the needs of science policy decision makers?

Lessons for improving connections?

What Next?

12:15 Adjourn

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THE NEGLECTED HEART OF SCIENTISTS: COMMENTARY ON SAREWITZ AND PIELKE

by Barry Bozeman

University of Georgia

Comments prepared for U.S.-Norway Workshop "Reconciling the Supply of and Demand for Research in the Science of Science and Innovation Policy," 12-14 May 2009 at in Oslo, Norway

Dan Sarewitz and Roger Pielke provide an excellent analysis of *the* crucial problem in science policy- the gap between the capacity for knowledge and the social utility of knowledge. As they have often done in past work, they choose the most intractable of analytical problems and then show us that the problem is not quite as intractable as we thought.

So much for commendations. No matter how well deserved, commendations have enervating effects. To paraphrase Oscar Wilde, "One must have a heart of stone to read accolades of friends without laughing." [1] Thus, in the remainder of this short essay, I raise three points. They are not really disagreements so much as questions and requests for amplification.

Problem 1: Unfortunate Economistic Thinking from the Most Unlikely Source.

It is entirely understandable, though no less unfortunate, that Sarewitz and Pielke (hereafter S&P)[2] frame their paper in terms of "demand and supply." Arguably, one of the significant problems in thinking about science outcomes and science policy is the difficulty of moving beyond economic models and concepts. Elsewhere, S&P (1999) refer to economics as the "imperial social science" and decry its tendency to drive out other theoretical approaches. As an avid reader of S&P, it seems to me that they are not anti-economics but rather that they are focused on ensuring that economics concepts and models not be stretched to the breaking point. Yet, by framing this entire discussion as "demand and supply," they are in danger of doing so themselves.

In most instances, what policy-makers mean by the "demand and supply of scientists"[3] is the match of the number of trained scientists in relation to the *market-based* demand for their work. This is an issue of long standing interest to policy-makers and understandably so. Indeed, the issue is in some respects a sub set of general supply-demand issues in labor markets and, thus, there is a body of well established theory to guide analyses of scientific human capital studies. While S&P (p. 9) tell us that "the notion of supply and demand functions for science helps to clarify the dynamic role of science in society," I suggest it has rather a muddying effect. They tell us (p. 6) that "the neglected heart of science policy…is how one might approach the problem of rigorously assessing the relationship between a research portfolio (or a set of alternative portfolios) and the societal outcomes that the portfolio is supposed to advance." While I am not confident that this is the *neglected* heart of science policy (many others have noted the mismatch between need and effort), I can certainly believe that is the heart. But this is not a problem of supply and demand and to cast it as such oversimplifies the problem and possibly leads down blind alleys.

The reason that the metaphor is inapt is that it misses a key ingredient. In conventional uses of supply and demand the driver is the marketplace. Even in the case of studies of the supply and demand of scientists, the focus is not on some ideal number of scientists required by the public interest but rather the number than can and should be supported in jobs produced by the market. While the relationship of scientific jobs to the market is in some modest respects reciprocal in its causality, the key point is this: it is a market-governed question.

1. For the pedants among us, I note that Wilde's quotation referred not to the accolades of friends, but to the death of Little Nell in Dicken's The Olde Curiosity Shoppe. I do not necessarily equate either Dan or Roger to Little Nell.

2. I do not necessarily equate either Dan or Roger to a large cap common stock index.

3. When I use the term "scientists," I am referring, as shorthand, to scientists, engineers, computer scientists, and mathematicians.

We could, of course, suggest that the S&P conception is simply an extension of the well worn metaphor "the marketplace of ideas." But this would be justifying a strained metaphor with a worse one. The whole point of the S&P paper is that public value often is sometimes ill-served by our public investments in science and technology. This implies, of course, that science policy is and should be about much more than market needs. Similarly, "the marketplace of ideas" implies some sort of invisible hand, a set of suppliers responding with rational self-interest to a set of market cues. I am confident that this is not what S&P urge, at least not in this paper.

To some extent, my objection to the supply and demand metaphor can be viewed as a quibble. After all, the authors tell us (p. 10) that "science policy decisions that strongly determine research portfolios…are likely to be made by people, and in institutions, that are distance from the interfaces between research and potential use." They understand as well as anyone the complexities of science policy and that it is decidedly *not* all about a marketplace of ideas. Nevertheless, I submit that the use of the supply and demand language undercuts the focus on a number of key elements. In particular, language driving us toward human capital metaphors risks an under-emphasis on social capital aspects of science and technology policy. The training and social linkages of scientists are vital and, from a micro perspective, at least as compelling as human capital issues in determining the individual's role in closing the gap between social needs and scientific investments.

Problem 2. Neglect of the Non-Scientific Determinants of Social Ills.

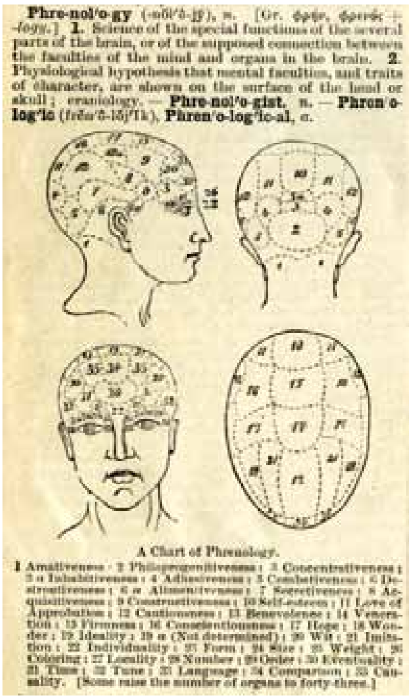
S&P are well aware of the fact that the ability of science to solve and remediate social problems is often limited. Science is not the all-conquering hero with social (or physical and natural) problems yielding inexorably to its force. They know this and, indeed, have taught us this (e.g. Sarewitz, 1996). But their model, the missed opportunity matrix (p. 12), seems not to take into account the extent to which science and knowledge problems are connected to other social levers. In many instance, the inability to solve social problems is not owing to a lack of "relevant information" or issues of "user benefit." In many instances there are social, demographic or environmental limits that overwhelm the ability to either envision or produce knowledge solutions. Their model should perhaps give more attention to these mitigating factors. To be sure, this is not easy. Take the classic example of mismatch: the U.S. health care system. To a large extent there are exactly the knowledge problems and mismatches that are of concern to S&P. However, this is only part of the picture. It is not even the largest part of the picture. Knowledge production seems to have much less to do with health outcomes than does the lack of health care access and coverage. Perhaps it is unfair to expect S&P to attack every aspect of social problem solving. They do talk about "institutional constraints" and "other obstacles." But when considering "missed opportunities" is there not a greater and more explicit *analytical* role for demographic, resources and political-institutional drivers of the utility and impact of knowledge?

Problem 3: The "Everyone a Phrenologist" Enigma.

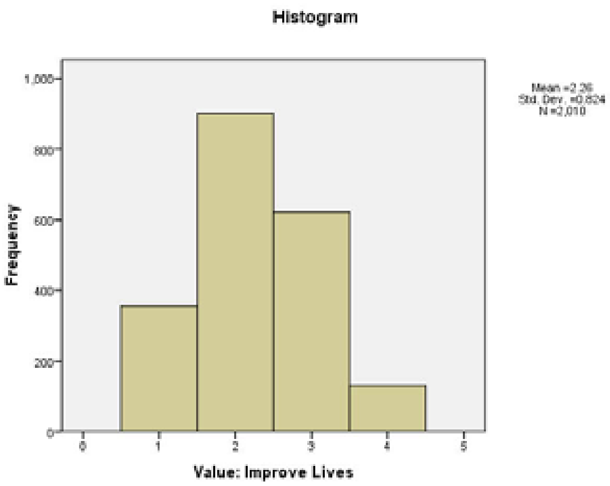
My final point is not really a criticism but a concern, a concern for science policy in general, not just the S&P analysis. Most science policy mavens, and probably many scientists, believe that there is a mismatch between knowledge resources, their deployment and social need. However, it is not clear exactly what steps help close that gap. Certainly, these issues are to some extent subject to massive exogenous shifts, political (e.g. Obama vs. Bush), economic (e.g. worldwide recession), and natural (e.g. natural disasters). But science policy analysts, reflexively action-oriented, want to know about the realm of the possible, the immediately possible. Policy analysts want to identify middle-gauge policy solutions.

Not surprisingly, the S&P conclusions section, the one with the prescriptions, is brief. Their "what is to be done?" includes developing better analytical frameworks, and they have given us a very good start on this. As good policy analysts they would have us direct our scholarly labors to "show that plausible alternative research portfolios might more effectively meet (the promises upon which scientific funding are predicated)" (p. 14). That is a useful goal, though a terribly difficult one, at least if we require research-based evidence. However, even this ambitious goal seems in adequate in some respects. If we begin to understand more about "the gap" and about how to identify better and more fruitful knowledge investments, who implements this new understanding and how do they do it? It is not just a matter of *convincing* policy-makers. While there are still some hidebound Polanyi disciples out there, it is certainly the case that many policy-makers already concern themselves with the social impacts of the science they promote. There is no deficit of worthy objectives. But even the pure hearted policy maker can be undone by the "everyone a phrenologist" problem.

The "everyone a phrenologist" problem dramatizes the extent to which many scientists are inured to social priorities, even when funding seems tied to social priorities. The point is this: if $10 billion were available for phrenology studies, then vast numbers of scientists would become phrenology researchers; that is, they would demonstrate in their proposals that the work they have been doing for decades is precisely what is needed for any advances in phrenology.



For now it is enough, more than enough, for science policy analysts to engage in developing tools that will cast more light on the relationship of resources-activity-and social impacts of science. But when we have that knowledge, what can policy makers do with it? Can they turn micro-focused scientific caterpillars into social butterflies? The findings in Table 1 seem suggestive.



Item: "An important value of science is to improve human life"

Key: 1= Strongly Disagree, 2= Disagree, 3= Agree, **4= Strongly Agree (5.4%)**

Sample: Research Value Mapping National Survey of Academic Scientists, a representative, proportional sample of STEM faculty in Carnegie Extensive Universities (n= 2,010).

References

Sarewitz, D. (1996) *Frontiers of Illusion*. Temple University Press.

Sarewitz, D. and R. Pielke (1999) "Prediction in Science and Policy," *Technology in Society*, 21, 2, 121-133.

DO WE NEED BETTER PREDICTIONS TO ADAPT TO A CHANGING CLIMATE?

by S. Dessai, M. Hulme, R. Lempert, and R. Pielke, Jr.

Dessai, S., M. Hulme, R. Lempert, and R. Pielke, Jr. 2009. Do We Need Better Predictions to Adapt to a Changing Climate? Eos, Vol 90, No. 13, pp. 111-112.

Many scientists have called for a substantial new investment in climate modeling to increase the accuracy, precision, and reliability of climate predictions. Such investments are often justified by asserting that failure to improve predictions will prevent society from adapting successfully to changing climate. This Forum questions these claims, suggests limits to predictability, and argues that society can (and indeed must) make effective adaptation decisions in the absence of accurate and precise climate predictions.

Climate Prediction for Decision Making

There is no doubt that climate science has proved vital in detecting and attributing past and current changes in the climate system and in projecting potential long-term future changes based on scenarios of greenhouse gas emissions and other forcings. The ability of climate models to reproduce the time evolution of observed global mean temperature has given the models much credibility. Advances in scientific understanding and in computational resources have increased the trustworthiness of model projections of future climates.

Many climate scientists, science funding agencies, and decision makers now argue that further quantification of prediction uncertainties and more accuracy and precision in assessments of future climate change are necessary to develop effective adaptation strategies. For instance, the statement for the May 2008 World Modelling Summit for Climate Prediction (http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit/Documents/FinalSummitStat66.pdf) argues that "climate models will, as in the past, play an important, and perhaps central, role in guiding the trillion dollar decisions that the peoples, governments and industries of the world will be making to cope with the consequences of changing climate." The statement calls for a revolution in climate prediction because society needs it and because it is possible. The summit statement argues that such a revolution "is necessary because adaptation strategies require more accurate and reliable predictions of regional weather and climate extreme events than are possible with the current generation of climate models." It states that such a revolution is possible because of advances in scientific understanding and computational power.

If true, such claims place a high premium on accurate and precise climate predictions at a range of geographical and temporal scales as a key element of decision making related to climate adaptation. Under this line of reasoning, such predictions become indispensable to, and indeed are a prerequisite for, effective adaptation decision making. Until such investments come to fruition, according to this line of reasoning, effective adaptation will be hampered by the uncertainties and imprecision that characterize current climate predictions.

Limits of Climate Prediction

Yet the accuracy of climate predictions is limited by fundamental, irreducible uncertainties. For climate prediction, uncertainties can arise from limitations in knowledge (e.g., cloud physics), from randomness (e.g., due to the chaotic nature of the climate system), and from human actions (e.g., future greenhouse gas emissions). Some of these uncertainties can be quantified, but many simply cannot, leaving some level of irreducible ignorance in our understanding of future climate.

An explosion of uncertainty arises when a climate change impact assessment aims to inform national and local adaptation decisions, because uncertainties accumulate from the various levels of the assessment. Climate impact assessments undertaken for the purposes of adaptation decisions (sometimes called end-to-end analyses) propagate these uncertainties and generate large uncertainty ranges in climate impacts. These studies also find that the impacts are highly conditional on assumptions made in the assessment, for example, with respect to weightings of global climate models (GCMs)—according to some criteria, such as performance against past observations—or to the combination of GCMs used.

Future prospects for reducing these large uncertainties remain limited for several reasons. Computational restrictions have thus far restricted the uncertainty space explored in model simulations, so uncertainty in climate predictions may well increase even as computational power increases. The search for objective constraints with which to reduce the uncertainty in regional predictions has proven elusive. The problem of equifinality (sometimes also called the problem of "model identifiability")—that different model structures and different parameter sets of a model can produce similar observed behavior of the system under study—has rarely been addressed. Furthermore, current projections suggest that the Earth's climate may soon enter a regime dissimilar to any seen for millions of years and one for which paleoclimate evidence is sparse. Model projections of future climate therefore represent extrapolations into states of the Earth system that have never before been experienced by humanity, making it impossible to either calibrate the model for the forecast regime of interest or confirm the usefulness of the forecasting process.

In addition, climate is only one of many important processes that will influence the success of any future adaptation efforts, and often it is not the most important factor. Our current ability to predict many of these other processes—such as the future course of globalization, economic priorities, regulation, technology, demographics, cultural preferences, and so forth—remains much more limited than our ability to predict future climate. This raises the question of why improved climate predictions ought to be given such a high priority in designing adaptation policies.

Alternatives to Prediction

Individuals and organizations commonly take actions without having accurate predictions of the future to support those actions. In the absence of accurate predictions, they manage the uncertainty by making decisions or establishing robust decision processes that produce satisfactory results. In recent years, a number of researchers have begun to use climate models to provide information that can help evaluate alternative responses to climate change, without necessarily relying on accurate predictions as a key step in the assessment process. The basic concept rests on an exploratory modeling approach whereby analysts use multiple runs of one or more simulation models to systematically explore the implications of a wide range of assumptions and to make policy arguments whose likelihood of achieving desired ends is only weakly affected by the irreducible uncertainties.

As one key step in the assessment process, such analyses use climate models to identify potential vulnerabilities of proposed adaptation strategies. These analyses do not require accurate predictions of future climate change from cutting-edge models. Rather, they require only a range of plausible representations of future climate that can be used to help organizations, such as water resources agencies, better understand where their climate change–related vulnerabilities may lie and how those vulnerabilities can be addressed. Even without accurate probability distributions over the range of future climate impacts, such information can prove very useful to decision makers.

Such analyses generally fall under the heading of "robust decision making." Robust strategies perform well compared with alternative strategies over a wide range of assumptions about the future. In this sense, robust strategies are insensitive to the resolution of the uncertainties. A variety of analytic approaches, such as exploratory modeling, have been proposed to identify and assess robust strategies.

Climate and Science Policy Implications

Given the deep uncertainties involved in the prediction of future climate, and even more so of future climate impacts, and given that climate is usually only one factor driving the success of adaptation decisions, we believe that the "predict-then- act" approach to science in support of climate change adaptation is significantly flawed. This does not imply that continued climate model development cannot provide useful information for adaptation. For instance, such development could further inform the plausible range of impacts considered when crafting a robust adaptation strategy. However, further scientific effort will never eliminate uncertainty; it may in fact increase uncertainty. For example, 3 decades of research on climate sensitivity (the global mean temperature change following an instantaneous doubling of carbon dioxide in the atmosphere) have not reduced, but rather have increased, the uncertainty surrounding the numerical range of this concept. The lack of climate predictability should not be interpreted as a limit to preparing strategies for adaptation.

By avoiding an analysis approach that places climate prediction at its heart, successful adaptation strategies can be developed in the face of deep uncertainty. Decision makers should systematically examine the performance of their adaptation strategies over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political, and cultural factors. They should choose a strategy they find sufficiently robust across these alternative futures. Such an approach can identify successful adaptation strategies without accurate and precise predictions of future climate.

Our arguments have significant implications for science policy. At a time when government expects decisions to be based on the best possible science (e.g., evidence-based policy making), we suggest that climate science is unlikely to support prediction-based decisions. Overprecise climate predictions can also lead to maladaptation if the predictions are misinterpreted or used incorrectly. From a science policy perspective, it is worth reflecting on where investments by science funding agencies can best increase the societal benefit of science. Efforts to justify renewed investments in climate models based on promises of guiding decisions are misplaced.

The World Modelling Summit for Climate Prediction called for a substantial increase in computing power (an increase by a factor of 1000, at the cost of more than a billion dollars) to provide better information at the local level. We believe, however, that society will benefit more from having a greater understanding of the vulnerability of climate-influenced decisions in the face of large irreducible uncertainties, and the various means of reducing such vulnerabilities, than from any plausible and foreseeable increase in the accuracy and precision of climate predictions.

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Please see Forum by S. Harrison and D. Stainforth, this issue. Readers may share their views on this topic by joining the online Eos discussion at http:// www.agu.org/fora/eos/.

TESTING THE BOUNDARIES BETWEEN THE SUPPLY OF AND THE DEMAND FOR RESEARCH

by J. Britt Holbrook

Department of Philosophy and Religion Studies

University of North Texas

Which research should we fund? This is one of the chief questions science policy aims to answer. Far from being susceptible to easy answers, however, it raises a suite of related questions: How do we *know* whether we are funding the right research? Can we expect a return on our investment? Of what sort? Are there any *benefits* to funding this research rather than that? Of what sort? What about the *risks* of funding this research? These questions are particularly difficult when they are asked with reference to basic research, which is not aimed at any particular utility. It is precisely because of the difficulty in providing answers to such questions that the National Science Foundation (NSF) has issued a solicitation for proposals to address the Science of Science and Innovation Policy (SciSIP):

> SciSIP will underwrite fundamental research that creates new explanatory models and analytic tools designed to inform the nation's public and private sectors about the processes through which investments in science and engineering (S&E) research are transformed into social and economic outcomes. SciSIP's goals are to understand the contexts, structures and processes of S&E research, to evaluate reliably the tangible and intangible returns from investments in research and development (R&D), and to predict the likely returns from future R&D investments within tolerable margins of error and with attention to the full spectrum of potential consequences.

SciSIP aims, in other words, to develop a science of science policy, a "community of experts" to whom we can turn for help in answering the question as to which research we should fund. This in itself represents quite an innovation in our policy for science, for there already exists a long-standing method of determining which research we should fund: peer or merit review.

NSF Merit Review

According to the annual *Report to the National Science Board on the National Science Foundation's Merit Review Process*, "The merit review system is at the very heart of NSF's selection of the projects through which its mission is achieved." In short, when answering the question as to which research should be funded, NSF turns (over 96% of the time) to the process of merit review. According to NSF's *Grant Proposal Guide*, "All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF who are experts in the particular fields represented by the proposal" (GPG, Chapter III). In other words, when trying to determine which research to fund, NSF turns to a community of experts. One might wonder, then, at the need for a second such community of experts in the science of science and innovation policy – unless, that is, there is some deficiency in the current pool of experts that prevents them from being able fully to answer the question as to which research should be funded.

NSF's merit review process evaluates all proposals through the use of two generic merit review criteria that ask: *What is the intellectual merit of the proposed activity?* and *What are the broader impacts of the proposed activity?* Although both proposers and reviewers display remarkable facility with describing and assessing the intellectual merit of the proposed research, describing and assessing the broader impacts of the proposed research is notoriously difficult. Perhaps the most obvious reason for this discrepancy between the Intellectual Merit Criterion (IMC) and the Broader Impacts Criterion (BIC) is that IMC asks proposers and reviewers a question that is directly relevant to their disciplinary area of expertise, whereas BIC asks them to describe and assess activities that go beyond their particular area of expertise. Whereas IMC asks scientific experts to judge the science, BIC asks scientific experts to judge the educational, infrastructural, multicultural, and societal benefits of the proposed activity – i.e., BIC asks scientists to make judgments about issues about which they may possess no relevant expert knowledge. Why would NSF ask scientists to judge anything other than science?

One of the main reasons behind the 1997 introduction of NSF's current generic merit review criteria was the desire to link public investment in science with societal benefits, to demonstrate, in other words, that the people were getting a good return on their investment. [For a brief description of the motivations behind the re-examination of NSF's merit review criteria, see the Task Force on Merit Review's Discussion Report (NSB/MR 96-15), Section I. Context of the Report. For a more detailed history of the development of NSF's new merit review criteria, including a "Key Events and Decisions Timeline," see the NAPA Report, p.p. 23-31.] Congress had passed the Government Performance Results Act (GPRA) in 1993. GPRA's purpose was to increase the focus of Federal agencies on improving and measuring "results," which would provide congressional decision makers with the data they require to assess the "relative effectiveness and efficiency of Federal programs and spending." The message that "results" are tied to funding was also reinforced when President George W. Bush took office by the President's Management Agenda (PMA), as well as the establishment of the Program Assessment Rating Tool (PART), designed specifically to tie GPRA to budget formation. It was largely in response to such demands for demonstrable results that in 1995 NSF adopted a new strategic plan, according to which, among the long-term goals of the Foundation was "the promotion of the discovery, integration, dissemination, and employment of new knowledge in service to society" [*NSF in a Changing World* (NSF 95-24)]. The goal of "knowledge in service to society" was meant to link NSF's goal of world leadership in science and engineering with contributions to the national interest. The 1997 introduction of the current merit review criteria was simply the next step in being able to show demonstrable "results." Yet NSF's response to this demand for demonstrable results had the unforseen consequence that scientists were now asked to judge not only science in their particular area of expertise, but also non-science in the form of proposed societal outcomes of the research.

A 2003 Report on the workshop "Research Policy as an Agent of Change" describes the situation thusly:

> Policies such as the Government Performance and Results Act, not initially designed specifically for R&D, change the politics of research policy by shifting emphasis to certain measured outcomes of research or the research funding process. Even those measures specifically designed for research, like the new NSF broader impacts criterion, can develop politics around the articulation of the standard and the ability of funding agencies and peer reviewers to evaluate such articulations. Arguably, the role of the broader impacts criterion is to get researchers out of their internalist arguments and connect their research beyond the narrow (academic) laboratory—in effect, creating a different kind of research politics that includes users, stakeholders, and others, and not just readers of scientific papers. (p. 22)

What this report stops just short of suggesting is that NSF's Broader Impacts Criterion actually requires a rethinking of the merit review process, a reevaluation of the idea that one's scientific peers alone are best suited to judge which research should receive funding. Perhaps "users, stakeholders, and others, and not just readers of scientific papers" are needed in order to judge the broader impacts of the proposed activity.

Blurring Boundaries

Because of its emphasis on impacts beyond those of simply producing more knowledge, BIC should promote reflection on whether a research program is responding effectively to a real social need. But over the last decade, BIC has routinely been interpreted rather narrowly as encouraging the promotion of science for the sake of science. For instance, BIC is now most often satisfied by including public education and outreach activities, with little consideration for whether these are really demanded by the social context.

How, then, might BIC be utilized in ways that enhance the supply of scientific knowledge that responds to a real societal demand rather than simply trying to create a demand for a knowledge supply that scientists themselves want to create? In 2007 Congress proposed its own answer to this question in the form of the America COMPETES Act, which explicitly ties BIC to the promotion of Responsible Conduct of Research (RCR) activities, such as mentoring post-doctoral researchers and instructing undergraduate and graduate students in the ethics of research. Such an answer, of course, interprets the question of the supply and demand of scientific knowledge as a question concerning the *quality* rather than the *quantity* of knowledge production. Instead of using BIC just to promote *more* science, Congress is expressing the demand for scientists to think in terms of producing *better* science.

Scholars who study science and innovation policy can help reconcile the supply of science and the demand for science by:

- identifying, interpreting, and articulating the demands of policy makers for the knowledge suppliers
  - this could include writing scholarly articles for other scholars who study science policy
  - but it must also go beyond such research for the sake of research and involve engaging policy makers, researchers, and other stakeholder groups
- helping knowledge suppliers articulate how their research meets the demands of policy makers
  - at the proposal writing stage of the research
  - during the research
  - in the dissemination of the research
  - retrospectively
- recognizing that the suppliers and demanders are not fixed entities, but will vary according to context – relation to the notion of boundary objects and organizations ….

WORKSHOP COMMENTS

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This is from my perspective as a behavioral researcher, so may be a little different from most participants. I here use the area of health as an example, but the problems exist across the behavioral disciplines.

Human behaviors of prevention and self-management play a leading role in the treatment of most diseases, including HIV, cancer, diabetes, and heart-disease. Conversely, risk-taking behaviors and inadequate self-management lead to about 1.2 million American deaths annually – a number that has not changed significantly between 1990 and 2000 – in spite of extensive attention by the behavioral research community. During this period, the community has seen rapid growth of evidence in the area of health behaviors. Unfortunately, due to inconsistent language across disciplines, this large volume of new research has had a limited effect in addressing the basic problems of human health. Behavioral science researchers are now recognizing that it is impossible to find and incorporate all related disciplinary knowledge, a problem that is increasing exponentially as genetic research is added to the mix.

Analogously, chemistry faced the same problem 140 years ago. Scientists attempting to understand the physical and chemical properties of elements and chemical compounds were faced with a mountain of seemingly unconnected facts. The solution was Mendeleev's periodic table of elements. ***The behavioral sciences now exist in a "pre-Mendeleev" era***, where true trans-disciplinarity is impossible due to human cognitive limitations. To link behavioral and variables, there is need for a tool that serves as a kind of periodic table for behavioral research, ensuring a common language among researchers. Such a tool must also simultaneously serve as a translational tool for non-expert policy makers, allowing policy makers to understand the current state of research and what problems have been solved.

In my own research I have developed such tools, whose objective is to automatically categorize and predict the relationships between constructs in a conceptual structure that would function like a periodic table for the health behavioral sciences. This research develops such a structure based on *nomological networks*, the relationships between unobserved constructs that form the basis of knowledge in the health behavioral sciences. Such a project increases researchers' ability to unify existing behavioral constructs across theories, allowing cleaner linkages to environmental and demographic variables.

SCHOLARLY SCIENCE POLICY MODELS, REAL POLICY, AND U.S. MISSION AGENCIES

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I. The linear model and scholarly alternatives

In the U.S., much of federally funded science has emerged from the ideas of one would-be shaper of science and innovation policy, Vannevar Bush. Bush's *The Endless Frontier* laid out a plan for a U.S. science system that occurs under the governance of one civilian-led body, that supports both basic and applied research, and that does so in the interest of meeting national goals, such as improved defense, health care, and industry. While Bush may have attempted to lay out a comprehensive system for U.S. science, which does fundamental theoretical work and successfully connects it to application and societal needs, the surviving part of his legacy was an emphasis on undirected basic research (Shapley 1985), that became codified under the assumptions of the linear model. However, in addition to policy makers who have objected to this framing of science policy (e.g. (Brown 1992)), many science and innovation policy scholars have criticized the idea of undirected basic research, arguing that directed research that can attend to the requirements of application will be more effective (Pielke Jr. 1998, Gibbons 1999, Sarewitz and Pielke 2007). Some scholars have posited alternative ideas including *Pasteur's Quadrant* (Stokes 1997), well-ordered science (Kitcher 2001), post-normal science (Funtowicz 1993), and Mode 2 science (Gibbons 1994). While this is by no means a comprehensive list of scholarly thinking on how to arrange science for societal benefit, the above do represent influential scholarly attempts to define or shape modern science policy, and to do so in a way that conceptualizes the relationship between science and society differently from the linear model (Table 1). The following paper, using data from case studies on U.S. federal agencies, is a short description and analysis of how such models apply to institutionalized science, ending with the argument that many scholarly propositions for science policy either lack descriptive ability to prescribe policies, or the accuracy to be consistent across differing cases and contexts.

Table 1: Characteristics of different science policy models

Model	*linear model (Bush, 1945)*	*Mode 2 (Gibbons, 1994)*	*Post-Normal Science (Funtowitcz, 1993)*	*Pasteur's Quadrant (Stokes, 1997)*	*Well-ordered science (Kitcher, 2001)*
Strategy	basic research put into a reservoir of knowledge	application-oriented	democratic	use-inspired basic research	Well-ordered science
Participants in decision making	scientists	heterarchical	extended peer network		occurs as if there was participation of a tutored public
Participants in science	scientists	socially-distributed	different sources of knowledge across the lay-expert divide	basic and applied researchers	science implementation occurs as if there was participation of a tutored public
Evaluation, quality control	peer review, evaluation by experts	new modes of quality control, more social accountability, reflexivity	expanded peer networks		occurs as if there was participation of a tutored public

The table describes the general characteristics of the models. In table 2, I input the results of three case studies on U.S. scientific mission agencies, the National Institute of Standards and Technology (NIST), the Naval Research laboratory (NRL), and the Agricultural Research Service (ARS), onto the same categories. The data on which these assessments are based from case studies on each agency at the program level, including interview work, performed between 2005 and 2008 (Logar 2007, 2008)

Table 2: Characteristics of case study agencies

Agency	*NIST*	*NRL*	*ARS-Global Change*
Strategy	Application/use-inspired basic research, with applied science	Application/use-inspired basic research, with applied science. Much basic research does go into a reservoir	Application-inspired, but mission may be flawed
Participants in decision making (below Congress)	Scientists with ample input from industry/ hierarchical	Scientists/ with input from customers/ budget decisions from navy leadership /hierarchical	Scientists with limited formal and informal input from farmers
Participants in science	Socially distributed between scientists and a technically literate user community	Scientists with limited military input	Scientists with limited farmer input
Evaluation, quality control	peer reviewed publications/ impact	Peer reviewed publications/ transition to Navy	Largely publication, but use by farmers is also regarded as success

While missing much of the nuance and variety of agency activities, table 2 provides general information on how different aspects of the science policy process conform to the predictions and recommendations of scholars. Although they do not conform to the linear model ideal of undirected basic research, it is also difficult to categorize the operations at these three institutions as falling into the recommendations of any idea more specific than Stokes's use-inspired basic research.

Vannevar Bush claimed that improvements in health care, the economy, and national defense rely on increased government funding for fundamental science. He described industry and government research as capital invested in "application of existing scientific knowledge." This scientific capital provides the wealth of knowledge that applied researchers in government and industry can draw on for their work.

Bush thought that while applied research was partly the role of federal science, government also needed to direct more funding toward researchers that are "free to explore natural phenomena without regard to possible economic applications" through the "free play of free intellects" (Bush 1945). The linear model, or reservoir model, that emerged, partly from Bush relies on a "fund from which the practical applications of knowledge must be drawn."

II. Science policy at federal mission agencies

For NIST, NRL, and ARS to pursue ideal linear model research, the strategies should for fundamental research should proceed without a consideration of application. Instead, they all expend a large amount of effort on connecting research outcomes to a product. The agencies are not merely depositing the research into a "fund" of informational capital. Even for fundamental work, NIST laboratories have developed means for considering application through a proposal mechanism called the Heilmeier questions, partly designed to aid researchers in assessing the future impacts of their work. NRL structurally resembles the linear research pipeline that Bush's ideas suggest, with research funding categories as discrete entities on a scale of increasing applicability. But, NRL processes encourage the representation of Navy concerns at every stage, thus supporting an integration of needs in its decisions. Research leaders often spoke of these processes as a necessary bridge between ivory tower academics and the working military. While scientists at all three institutions support academic curiosity and high-risk research, these concepts were also integrated with the idea of application.

With the exception of the linear model, application-oriented models share the idea that evaluating possible applications for research during the prioritization process will lead to increased likelihood of benefit. Each of the scholars agrees that for research to be effective, decision makers must address the concerns of their constituents. The three agencies I have do studied support this; decision makers both speak to the importance of working to meet demand side needs, and incorporate policies for doing so.

The linear model dictates basic research that is disciplinary, removed from influence, and without consideration of use. On the other hand, Mode 2 science calls for research that is transdisciplinary, strongly influenced by nonscientist decision makers, and explicitly considerate of use. Much of NRL pursues fundamental research that is disciplinary, weakly influenced by outside concerns, and considerate of use. However, the NRL works within its system because first, its basic research considers use to the satisfaction of its customers. Some of NRL's customers are not interested in a product, but instead judge the research outcome as successful if it plausibly leads to a long-term innovation that can aid the Navy. Second, while basic research is conceptually separated at NRL, it is part of an undertaking that works as a whole to deliver products to users by connecting fundamental work to technology development and Navy requirements.

In fact, well-ordered science, post-normal science, and Mode 2 science all dictate increasingly democratic mechanisms in the science decision-making apparatus. Within the programs I have studied, "democracy" is limited to structures for enabling institutional responsivity to identified users. Given that these are the people most interested in, and affected by, the outcomes of mission science, the principle of affected interests (Dahl 1990) dictates that decision processes include them. This also highlights the importance of context. Sometimes, full democratization is not necessary for effective outcomes, such as in cases where the context of application can be acceptably addressed without the inclusion of non-technical publics.

The institutional decision makers I have interviewed defined successful mission science as that which could plausibly enable utilization by the supply side. NIST, NRL, and ARS have all been successful, and all have mechanisms in place that encourage this success. According to the idea of reconciling supply and demand (Sarewitz 2007), all three agencies do have successes in produce science that matches information supply with user demand.

If one were to define the means of programmatic success as conformance to a particular scholarly model, then many federal programs fail. However, they can be successful in achieving the outcome that the models support: useful science. Stokes's broad idea for use-inspired research resonates because it describes a general ideal for research within the social contract. These institutions also support a weak reading of well-ordered science, where democratic outcomes need to be emulated, but not necessarily instituted. NIST, NRL, and ARS attempt to integrate public concerns into every stage of the process, with some success. In fact, the case studies agree with Mode 2 in this as well.

Mode 2 dictates that the context of application should shape the conduct of science at every stage in the process. However, the way it happens neither consistently takes the form, nor is it as extensive, as Mode 2 authors predict. A large part of this is due to the context in which these agencies operate. The bureaucratic structure of these institutions does not easily support the more fluid, less-rigid kind of science in *The New Production of Knowledge*. While this larger context could change, the agencies are currently working within their flexibility to pursue useful research outcomes.

Post-normal science could facilitate positive outcomes when stakes are high and outcomes are uncertain, and the characteristics of Mode 2 science do have the potential to encourage application. However, not all of these things are necessary for useful science. Instead, the important task for mission agencies is working within their constraints to instill considerations of application in different stages of the decision process. Both NRL and NIST follow numerous successful strategies for meeting their missions. The most important way they do this is by integrating user concerns to motivate and define application-oriented research in projects ranging from the fundamental to technology development. Of course the important consideration for mission agencies is not simply that they are considering application, but the manner in which they are doing so. Although agency personnel are responsible for agency decisions on science, including explicit participation of users in the process, and non-participatory consideration of the demands of users, can enrich mission science by enabling research leaders to connect their research to a positive outcome.

Given the importance of context, it is hard to envision a model that is both sufficiently descriptive to provide actionable prescriptions for policy makers, and broad enough to be utilizable in a variety of institutional situations. For example, many institutions and scientific leaders have subscribed to the ideas of Bush's linear model, but few examples exist of research programs that have been first, truly uninfluenced by considerations of need, and at the same time, successful in contributing to need. In the same way, ideas such as Mode 2 science lay out a set of criteria that are descriptive and broad, but not sufficiently so. First, as agencies such as NIST show, it is extremely possible to be successful without following all of the recommendations of Mode 2 authors (see table 3).

The characteristics of Mode 2 science, as described by Gibbons et al. (1994), include a context of application that takes user problems into account, social accountability, heterarchy, transdisciplinarity, socially distributed knowledge production, and norms for quality control that transcend academic peer review. Table 2 summarizes how the agencies fit within these categories. In most cases, agencies do not cleanly fall into a yes or no category, but the table does represent the general trend.

The agencies all represent science efforts oriented towards application, but do so without heterarchy or transdisciplinarity. For quality control and social diffusivity, results were mixed, and the agencies largely operate with limited social accountability. They make policy with the users' needs in mind, but without direct participation in prescription. When agency researchers do not define research in terms of the specific problem they are addressing, they point to a broad field of application.

Table 3: Agency fit to Mode 2 claims

Mode 2	NIST	NRL	ARS
context of application	yes	yes	yes
social accountability	limited	limited	limited
heterarchy	no	no	No
transdisciplinarity	no	no	No
social diffusivity	yes	limited	limited
quality control beyond peer review	yes	yes	limited

Aspects of agency work do occur in a context of application, when it is defined as a knowledge system that works toward information, "intended to be useful to someone." This use is integrated into decisions from the beginning of the process, which considers the interests of many actors. However, not all of the agencies' focus is strictly Mode 2 science. In Mode 1 science, scientific curiosity defines problems. Many of the interviewees within NIST and NRL spoke of this as one of the criteria they were considering, along with application, in making their decisions. Although many decision makers are application-minded, application does not steer the process entirely.

The lack of strong Mode 2 science in government agencies, even in those with missions that direct them to help certain users, is not a negative outcome. The single funding source of government science implies a certain amount of control that must come down from the popularly elected decision makers at the top, and will affect the implementation of Mode 2 strategies. Second, while the case studies relate to many of the Mode 2 characteristics incompletely, they do represent progress towards attaining the most important aspect of Mode 2 science, which is the context of application. In *The New Production of Knowledge*, the authors wrote, "in this mode, knowledge produced is already shaped by the needs and interests of some, at least, of the potential users" (54) (1994). The context of application, in which user needs shape the research, is the central tenet of Mode 2. Other characteristics, such as social accountability, are the characteristics of this context. Although not all of these attributes are necessary in every case of Mode 2, the authors contend that their presence is necessary for coherence and organizational stability.

Mode 2 science is "intended to be useful to someone whether in industry or government, or society in general and this imperative is present from the beginning" (4). While the authors claim to be taking no position on the desirability of implementing Mode 2, Paul David makes a strong case for the existence of a pro-Mode 2 policy stance in the language of *The New Production of Knowledge* (David 1995), According to the authors, the growth of Mode 2 "calls into question the adequacy of familiar knowledge producing institutions," (Gibbons 1994), including government research institutions. However, since an incomplete Mode 2 is acceptable in the authors' discussion, and since federal agencies can work within a context of application without fully implementing Mode 2, Mode 2 only questions the adequacy of those institutions that fall firmly into the Mode 1 category and thus do not consider application. While Mode 2 science might be one way of enabling useful information, all of the characteristics of Mode 2 science are not necessary for the production of such information. The case studies I have performed show that the agencies can benefit their users without fully implementing Mode 2.

Given that NIST, NRL, and ARS, are all "familiar knowledge production institutions", to the point where they have all existed for over 75 years, one would think that their performance would be questionable and their operations would be closer to Mode 1 science, since Mode 2 is characterized as an emerging phenomenon. Instead, they all represent some hybrid point on the spectrum between Mode 2 and Mode 1 science. This may be where government science is most like Mode 1, or normal, science. In fact, it may be difficult or even impossible for any government mission agency to be truly Mode 1, and thus divorced from application, or truly Mode 2. Because all government groups work within the hierarchical framework of government, they do not possess the socially diffuse decision structures that Mode 2 dictates.

When the relationship between other models' claims and the realities in federal agencies are examined, similar results to that of Mode 2 occur. The concept of postnormal science is, in some way, an extension of the "principle of affected interests." In his book, *On Democracy*, Robert Dahl (1990; 64) (Dahl 1990) states that the principle means that, "Everyone who is affected by the decisions of a government should have a right to participate in that government." In arguing for a post-normal science, Funtowicz and Ravetz maintain that as the systemic uncertainty and the decision stakes increase, so should the tendency to include more democratic participation through "extended peer communities," that "span the lay-expert divide" (Funtowicz 1993). However, the relationship between stakes and involvement does not consistently play out in reality. One issue is the question of "high stakes for whom?" Measurement and standards issues are high stakes for NIST's chief constituents in U.S. industry, but do get much attention from the general public. At the same time, global change research is typically represented as a high-stakes, high uncertainty problem, but the low willingness of farmers to participate means that, within that community, stakes are so low that agricultural organizations have at times been unwilling to send representatives to ARS Global Change planning workshops. While, on surface, the ARS research is more of a classic post-normal science problem, NIST more consistently incorporates affected interests through the willing participation of demand side groups.

Kitcher's idea of well-ordered science reaches a level of abstraction that makes it difficult to assess whether real world institutions meet his recommendations. Kitcher makes no policy recommendations, instead positing democratic mechanisms as a means for effective science. Kitcher actually leaves room for outcomes that emulate the result of democratic processes when he writes, "the proper notion of scientific significance to be that *which would emerge* from ideal deliberation among ideal agents," (Kitcher 2001) [emphasis added]. Because Kitcher is so abstract, it complicates assessment of whether a scientific program is well-ordered. For example, one could argue (tenuously) that the American electoral system is a successful approximation of ideal deliberation.

In the case studies, there are policies for including the interests of a limited public in many of the decisions, but they are never "democratic" in the strict sense of the word. Part of the reason for this lies in accountability; the executive branch can only be effective if there is someone who is responsible for decisions when they are evaluated. Many of the mechanisms in institutions such as NIST, NRL, and ARS are only an approximation of well-ordered science. They involve the limited participation of a restricted (but invested) public, but the agency staff makes the final decisions.

Stokes framed his ideas for "Pasteur's Quadrant" as "completing the linear model." (Stokes 1994) The center of Stokes's argument is that, in framing basic research as both a quest for fundamental understanding and an undertaking that is free from considerations of use, the linear model sets fundamental science and consideration of use as mutually exclusive. The scientific work within ARS, NRL and NIST indisputably focuses on eventual use, and this fall within the realm of use-inspired basic research. The former Director of NIST invoked Stokes when he said, "we are the closest thing that our government has to use-inspired basic science." (Jeffrey 2007), and National Research Council evaluations of DOD basic science categorize it as occurring within *Pasteur's Quadrant* (NRC 2005). However, while Stokes provides a useful conceptualization of theory-driven, application-oriented research, Pasteur's Quadrant is not explicit about how decision-making should occur. Thus, it is not able to dictate a means for prioritizing, evaluating, or implementing the idea. The broadness of the concept allows institutions to utilize it as a rough guide for thinking, but cannot dictate behavior.

III. Conclusion

As scholarly models get more descriptive and prescriptive, it also becomes more difficult for a institution to conform. Mode 2 does not provide a clear set of recommendations, and the degree to which an institution is Mode 2 is almost always debatable. At the same time, it is the most concrete of the science policy models I have examined. For other models, as the amount of description goes down, the ability to prescribe actionable policies decreases with it.

Because of the implausibility of developing generalized models for dictating science policy, science policy scholars who are looking to improve decisions should look more to finding the empirical examples that work in certain situations, and providing them not as a recommendation, but as one in a range of alternatives that institutions can utilize in developing their science policies, adapt as needed, or attempt and then discard. Scientific decision makers can benefit from broad guidelines and ideas, such as use-inspired basic research, active engagement with user groups, and the instillation of mechanisms that can encourage application-orientation during project design, prioritization, implementation, and evaluation. However, beyond these guidelines, concrete explanations of how other institutions succeed may aid decision makers more than attempts at detailed, generalizable models for science policy.

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IS EFFECTIVE RECONCILIATION ALWAYS DESIRABLE? PROBLEMATISING THE SUPPLY AND DEMAND MODEL AND ITS QUEST FOR UTILITY

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The relationship between science and society has been widely debated in recent years. In an age when expert knowledge is "tightly woven into the very fabric of our existence" (Fischer, 1990, p. 13), scholars and practitioners alike have suggested that scientific experts need to test the validity of their knowledge claims outside the laboratory. Rather than approaching the world of science as separate from society, there is today an extensive literature that seeks to hold science accountable to its public constituencies. Post-normal science (Funtowicz & Ravetz 1993), citizen science (Irwin 1994) and co-production (Jasanoff 2004, Lemos & Morehouse 2005) are just some of the many concepts currently employed to characterise this new social contract for science. Of central importance to all these concepts is the idea that science cannot function in isolation. Instead of building the scientific claim to authority on its presumed autonomy from societal context, a growing scholarship today seeks to make science more "socially robust" (Nowotny et al. 2002) through direct engagement with societal context.

Sarewitz's and Pielke's (2007) supply and demand model brings this scholarly debate to the domain of science policy. By asking scientists to respond to the knowledge needs of societal decision-makers, Sarewitz and Pielke seek to improve the societal outcomes of science policy decisions. In this brief paper I want to discuss whether the supply and demand model always functions as a good guiding principle for science policy decisions. I do so by adding two questions to the equation. Firstly, I ask *whose* knowledge needs that are taken into account by the supply and demand model. Considering the range of possible users of scientific information and their potentially different views on desirable societal outcomes, the reconciliation process appears more complex and politically contested than implied by the supply and demand model. Secondly, I introduce a temporal perspective to Sarewitz's and Pielke's framework and ask *when* or within which time frames we should assess the effectiveness of the reconciliation process. Does the supply and demand model imply that science always should prioritise immediate and explicit knowledge needs in society, or is there still room for research that has no immediate demand function?

For *whom* is science useful?

A central question underpinning the supply of and demand for knowledge model is how to know if we are doing the right science. According to Sarewitz and Pielke (2007, p. 6), "just doing research on a problem of societal importance says nothing directly about whether or under what conditions the research can effectively contribute to addressing that problem". They instead suggest that the supply of scientific knowledge has to be assessed in relation to the knowledge demands among decision-makers in society. The *right science is*, from this vantage point, research portfolios that effectively meet the knowledge demands in society. While the supply and demand model hereby extends the accountability of science beyond scientific peers, it offers little scope for problematising *whose* knowledge demands that are served by science. The question of *which* societal groups science should be accountable to, is left unanswered. Although Sarewitz and Pielke (2007, p. 12) recognise the diversity of potential users of scientific information, and thus call for a "demand side assessment" that identifies relevant stakeholders, their model offers no normative guidance on how to prioritise between the political preferences and social choices built into research portfolios. Science policy decisions are *right* as long as they serve a clearly defined demand function in society.

This rather instrumental interpretation of useful science departs from a broader trend in the science and technology studies literature that, in recent years, has set out to *democratise science*. At the heart of this trend is the concern that science has failed to live up to its promise to work for the benefit of society at large. Critical scholars have argued that science too often serves an ideological function of legitimising the interests and decisions of societal elites (Fischer 1990). By framing social problems in technical terms issues of meaning are *closed down* from public debate, ruling out alternative political visions (Stirling 2007, Wynne 2007). Although scientists themselves may not deliberately contribute to this instrumental use of their work, there is today a mounting pressure to, in the words of Jasanoff (2003, p. 240), "make explicit the normative that lurks in the technical", and to hold science accountable to the implicit social choices built into certain research priorities and agendas.

While Sarewitz and Pielke (2007, p. 7) indeed recognise that the supply of science often is responsive to the presence of a well-articulated demand function, and that such responsiveness may lead to a preferential capture of benefits by certain groups, the supply and demand model does not allow us to question such interplay. In the science and technology studies literature, however, many scholars are today examining ways to expose how science is used in society. In order to turn science into a truly public good, a growing scholarship is today asking scientists to *open up* their knowledge claims to the views and concerns of citizen groups (e.g. via consensus conferences, stakeholder dialogues, citizen juries). Only when science and technology decisions are discussed and justified in public is it possible to build public acceptance for science policy decisions. Hence, in this literature the supply and demand model is taken one step further. Of interest is not so much how effective the reconciliation process is, but how *legitimate* it is.

While central to democratic decision procedures, legitimacy is an elusive concept that complicates the supply and demand analysis. In scholarly circles legitimacy has been defined as "the acceptance and justification of shared rule by a community" (Bernstein 2005, p. 142) and approached both descriptively and prescriptively. A descriptive or sociological account of legitimacy is concerned with how well rules and institutions correspond to the culturally and historically contingent belief systems in particular political communities. From this perspective rule is legitimate when its subjects believe it to be so. Prescriptive theories of legitimacy, by contrast, set out general criteria against which the right to rule can be appraised. Legitimacy is in this context a normative quality attributed by political theories to certain political systems and specific rules and principles. In the literature on *scientific democratisation*, scholars tend to advance a prescriptive account of legitimacy derived from deliberative democratic theory. From this vantage point, decisions about science are legitimate only when *all* those potentially *affected* by the decision are given equal and meaningful chance to test and accept them (Benhabib 1996).

While the deliberative conception of legitimacy only represents one of many prescriptive accounts, it could add a normative dimension to the supply and demand model. Organised around a set of procedural virtues (e.g. inclusiveness, fairness, unconstrained dialogue), the deliberative ideal allows us to assess the legitimacy of certain research portfolios. Whether it functions as a good guiding principle for science policy decisions does, however, remain an open question. Since all those potentially affected by science policy decisions cannot participate in free and open deliberations at the same time, a normative assessment of *legitimate reconciliation* introduces a range of practical challenges to the decision process (e.g. fair representation of views and concerns, securing free and inclusive reason giving). Furthermore, developed as a normative ideal among democratic theorists, the deliberative conception of legitimate science policy decisions is not insulated from critique and can thus be challenged by alternative models of democracy. Hence, before introducing a normative dimension to the supply and demand model, the normative ideal itself needs to be put under serious scrutiny and debate.

However, despite the many practical challenges tied to the deliberative ideal, efforts to *democratise science* highlight the risks of an instrumental understanding of useful science. Beyond the projection of normative ideals, such risks could be addressed through descriptive legitimacy studies. Such studies would rest upon empirical analyses of the social circumstances under which certain research portfolios gain public acceptance and credibility. While descriptive accounts of legitimacy could help science policy decision makers to make less instrumental decisions, they offer no absolute account of legitimacy. Tapping into a social constructivist research tradition, this approach would rather enrich the understanding of how discourses and practices of legitimacy are socially constituted and contested across time and contexts.

When **should science be useful?**

Sarewitz's and Pielke's supply and demand model emerges as a critical response to the *linear model* of science which ties societal progress to the pursuit of basic research performed without thought of practical ends. Drawing upon the supply and demand metaphor, the authors describe the linear model as *science-as-a-self-regulating-market*. "From this perspective, the supply of scientific knowledge is best generated without any connection or attention to demand for particular types of knowledge" (Sarewitz & Pielke 2007, p. 7). In exchange of autonomy and government funds, such self-regulating research holds the promise of delivering discoveries and technological innovations necessary for a prospering society. While this idealised science-society relationship underpinned Western science policy in the period after World War II, most scholars would today agree that the linear model is hopelessly outdated and even misleading.

According to Sarewitz and Pielke (2007, p. 8), most technological innovations in the post World War II era were by no means the result of autonomous basic research. Rather, successful links between research portfolios and technological advance are better explained by strategic decisions to focus public sector resources in particular areas of science. In cases with less public steering, the connections between basic research and societal application have been more serendipitous. The authors use US climate change research as their prime example in this context. The far-reaching studies of the global carbon cycle supported by the US Global Change Research Programme (USGCRG) since 1989 have been guided by a scientific desire to expand fundamental understanding rather than utility. Although the scientific achievements under this programme have fed knowledge and data into the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), and hereby indirectly informed the international negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), Sarewitz and Pielke approach the USGCRG as a typical example of basic science with poor connections to utility.

While the large public investments in basic climate research indeed can be questioned, the authors' motivation for changed research priorities is problematic for at least two reasons. Firstly, their supply and demand model lacks a temporal dimension. If all science policy decisions were guided by the knowledge demands articulated by societal stakeholders, the contemporary understanding of climate change as a social problem would most likely not have come about. When Svante Arrhenius examined links between human fossil fuel burning and atmospheric concentrations of carbon dioxide in the late 20th century, there was little societal demand for his enhanced greenhouse theory. Similarly, when Charles David Keeling erected the first permanent measurement station for atmospheric carbon dioxide on Mauna Loa in Hawaii in 1957, there were few public funding agencies that found it useful to support his work. Nevertheless, the findings from Arrhenius' mathematical computations and Keeling's atmospheric measurements became central for the contemporary understanding of anthropogenic climate change, and are therefore today approached as vital (and highly useful) scientific achievements.

Although Sarewitz and Pielke (2007, p. 7) acknowledge that fundamental achievements in knowledge often have broad application beyond anything that could be anticipated if the time scale is long enough, they argue that such links between inquiry and utility are too serendipitous to guide science policy decisions. Naturally, all research funds cannot be spent on vague promises of long-term application. In many cases it does, indeed, seem highly reasonable to demand that public funding is used to address immediate social needs. However, if all scientific research is funded on the basis of its utility, how can we guarantee a continued space for long-term inquiry and reflection? This question lies at the heart of my second objection to the supply and demand model. If we expect all science to be useful, and if its usefulness is determined by the knowledge demands articulated and voiced today, we run the risk of turning science into short-term consultancy. Also this risk can be exemplified by the contemporary funding of climate change research.

In parallel to the rise of climate science programmes such as the USGCRP, the political interest in climate change has in recent years generated a wide range of research that seeks to provide useful policy input to the negotiations on the UNFCCC and the Kyoto Protocol. Following the logic of the supply and demand model, investments in such research are effective since they respond to a demand for policy-relevant science advice articulated in the UN negotiations. However, if all climate policy research was guided by the immediate knowledge demands in multilateral circles, there would be little scope for science to explore policy futures beyond the UNFCCC setting. The societal demand for climate information may very well be much broader and diverse, as implied by Sarewitz and Pielke (2007, p. 11). However, if alternative demands are not articulated, how can the supply and demand model give support to alternative research agendas?

In 1981 the critical scholar Robert Cox made a seminal distinction between problem-solving and critical research. Problem-solving research takes the world as it finds it, with prevailing power relationships and institutions as the given framework for action. While this research tradition seeks to guide tactical actions and increase the efficiency of the existing institutional framework, Cox (1981) argued that critical research stands apart from the prevailing order and asks how it came about. Unlike problem-solving theory, this latter research tradition calls contemporary institutions and power relations into question and allows for a normative choice in favour of alternative social and political orders. Even if Cox's distinction may appear simplistic and stylized, it is rather safe to assume that the supply and demand model would favour the problem-solving research tradition. Since decision-makers often need answers to questions of immediate policy relevance, there would be little demand for research that calls the social order into question. Hence, the supply and demand model runs the risk of undermining the long-term reflection and critical scrutiny often associated with science.

Whether this dilemma can be resolved by introducing a temporal perspective to the supply and demand model remains an open question. If we can establish links between critical inquiry and social utility in the long run, this research tradition may very well be given priority in science policy decisions guided by societal demands. However, if there is no apparent demand function for critical research, should we abandon this central scientific task all together or is there still room for research that is not asked for?

Conclusions

The discussion advanced in this brief paper touches upon a fundamental question invoked by the supply and demand model. Namely, what is the role science in society? While this difficult question is far from resolved here, the supply and demand model makes a strong case for social utility. A small portion of the overall research portfolio may still advance scientific understanding for its own sake. However, Sarewitz and Pielke (2007) note that the lion's share aims to contribute to desired societal outcomes. Against this background, their supply and demand model seeks to maximise the societal outcomes of different research portfolios. While this pragmatic approach taps into a broader science policy trend in Western societies (cf. Nowotny et al. 2002), it lacks the normative dimension necessary to critically discuss the desirability of this trend. I have in this paper introduced two questions to the supply and demand equation that highlight potential problems resulting from an overemphasis on utility. Rather than reducing the role of science to a simple supplier of knowledge demanded by society, I argue that science also has a critical task and long-term responsibility to assess who benefits, when and how from such outcomes. Hence, instead of merely accepting the call for social utility as a given guiding principle for future science policy decisions, we need to be careful and critically reflect where it takes the academic endeavour.

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REMARKS ON THE CONFERENCE QUESTION:

"HOW CAN SCHOLARS WHO STUDY SCIENCE AND INNOVATION POLICY CONTRIBUTE MORE EFFECTIVELY TO THE NEEDS OF POLICY MAKERS FACING DECISIONS ABOUT SCIENCE AND INNOVATION POLICY?"

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Challenges to policy scholars

Science and innovation policy" encompasses an enormous diversity of issues and processes, matched by an equally numerous and diverse set of agencies and actors who conceive, advocate, and implement science and innovation policies. In the United States science policy processes are distributed broadly among the public and private sectors, and constitute a vast marketplace of ideas and initiatives. What structure exists in this broad set of activities has emerged more or less spontaneously as the result of numerous individual interactions among the producers and consumers of technically intensive goods and services. In such an environment, the first challenge to scholars is to establish a vocabulary and a conceptual structure in terms of which the status of specific processes can be analyzed and communicated. The second challenge is to form enduring traditions of communication and engagement that enable joint efforts that accumulate and preserve relevant knowledge. The third and perhaps greatest challenge is to forge links to the multiple communities of practice along which the products of scholarship can flow and become effective.

Questions arising from the Sarewitz/Pielke paper

The Theme Paper for this conference – "The neglected heart of science policy: reconciling supply of and demand for science" by Sarewitz and Pielke, jr. (Environ. Sci. Policy 10, 5-16, (2007) referred to as SP in the following) – is a credible response to the first challenge. The authors identify an easily visualized and familiar conceptual structure of supply and demand that suggests questions that can be asked and approaches to finding answers. Such a pre-defined structure is a necessary condition for an objective and cumulative scholarly product. It is not a unique structure, nor need it be. The authors make it clear from numerous cautionary statements and analytical sketches that they mean the supply/demand paradigm to be a tool, probably one among many, and not a complete solution to any particular policy issue. From this perspective certain classes of questions follow naturally: Is there a logically prior structure in which the uniqueness or appropriateness of this tool and others can be analyzed? Are there intrinsic features of this tool that guide its use? How effective is this tool likely to be in rising to the challenges of the science and innovation policy universe?

The Theme Paper includes brief discussions of many side issues that signal the authors' awareness of the limitations of their central supply/demand paradigm. How important these issues are to the overall needs of policymakers is not easy to assess using only this paradigm, and additional attention is warranted to the broader context of these ideas.

How central is the supply/demand issue?

The existence of a logically prior structure is implicit in the supply/demand model itself. It assumes a marketplace with well defined (or at least approximately defined) providers and consumers and, as argued by Sarewitz and Pielke, it implies significant policy inefficiencies that occur when supply and demand are not matched. How the model is used and whether it is useful clearly depend on how well the marketplace model actually fits the science and innovation policy universe. Problems of reconciliation of supply and demand for science may be a neglected part of science policy, but are they indeed the 'heart' of science policy? That is an assumption to be tested. Accepting the supply/demand process as the dominant feature of policy behavior may lead to an under-emphasis on behaviors at least as critical to successful policy-making.

An example of a broad class of possibly under-emphasized behavior appears at the outset of SP, who assert that "While some research is not expected by anyone to have a result other than the advance of scientific knowledge, such work is an extremely small portion of the overall science portfolio." While this statement is literally true, it misportrays the significance of "pure science" in the science policy universe. SP analyzes the validity of the "autonomous science argument" that "the creation of scientific knowledge is a process largely independent from the application of that knowledge" and find it wanting. That is, "[e]mpirical studies of the complex connections between research and societal applications give little support to" this conception. What is important, however, is not whether this picture accurately describes how science functions in society, but whether belief in it significantly affects the behaviors of important policy actors. SP's admission that the autonomous science conception "has had enormous political value for scientists," is an important indicator of the significance of this idea in actual policy making.

Beyond procedure

This example suggests an aspect of policy complementary to what might be called the 'proceduralism' of the supply/demand paradigm. While science policy certainly requires assessments, for example, of the information needs of 'science consumers' seeking to solve societal problems, it is also remarkably sensitive to psychological, cultural, and political attitudes that may be entirely unjustified by empirically based analyses of the actual state of affairs. Attempts to form and implement policies based only on a procedural paradigm, ignoring or dismissing as pathologies such 'ephemeral,' 'accidental,' or 'irrational' considerations as current cultural or political fashions, may work within a small community of practice, but fail if policy success depends on broad public acceptance. One of the fascinating aspects of climate science policy is the overwhelming influence of such factors on stakeholder behavior. All highly salient science policy issues display these features, from human space exploration to stem cell research. Much rhetoric in science policy forums deplores the irrationality of stakeholder behavior, and yet this behavior is part of the policy landscape that must be taken into account as objectively and with the same attention to tools and methods as the matching of science suppliers and science consumers.

Behavioral science as essential to the science of science policy

The introduction of a paradigm such as the supply/demand model is clearly an attempt to provide an objective basis for policymaking, but its usefulness to policymakers has two sides. Its procedural side, complete with "missed opportunity matrices" and inventories of market participants, is appealing because its tasks can be carried out without regard to advocacy and politics. But such procedures obviously create tools for dealing with idiosyncratic, random or transient behavior and this aspect of its functionality deserves as much analytical attention as the rational procedural aspect, and perhaps more. Most of the discussion of SP treats these behaviors as problems to be overcome by better processes that bring together the providers and the users, but the existence of better processes does not by itself guarantee policy effectiveness.

Workforce challenges

A second broad dimension of science policy that is related to the SP analysis, but is not emphasized in the paper, is the nature and status of the technical workforce. The technical quality of the activities that are the object of science policy make it possible to identify a reasonably specific population of providers – scientists, engineers, technicians … – who are the "suppliers" in the supply/demand paradigm. This technical quality entails specialized education, training and credentialing that is a common feature of professions and brings education and workforce issues into the science policy universe. Consequently, it is necessary to include these educational products among the technical goods and services in the marketplace picture of science policy. It is simply not possible to separate the supply of scientific knowledge from the supply of people who can deliver it.

The SP supply/demand framework lends itself well to the analysis of many technical workforce issues, and indeed labor economists traditionally use market models and tools for this purpose.

All such models are stressed by contemporary rapid changes in the nature of work brought about by globalization and information technology, and technical workforce analysis may be under the greatest stress of all. In most developed countries challenges in understanding, creating, and maintaining a technical workforce matched to national needs are viewed as more important for science policymakers than deciding what research projects or programs to fund.

The ambiguity of outcomes

The pursuit of Kitcher's "well-ordered science" as described in SP, postulates "ideal deliberators" on whom the burden rests of providing content for the negotiation of agendas, strategies and policies. The deliberators would represent the priorities and interests of the entire range of stakeholders who stand to benefit from the policies they construct. Kitcher's notion of a procedural surrogate for such deliberators distributes the burden of content back to the stakeholders through a representative process that would seem to imply a kind of grass-roots omniscience. In fact the concept of what is wanted, even by well-educated and experienced professionals, is extremely vague. This is a weakness of most policy discussion: we assume that a desired outcome can be identified unambiguously.

The problem here is not so much that most people cannot say with clarity what they really want to improve their lives in the medium to long run. It is that what they (we) want is not conditioned by immutable principles. Beyond rather straightforward basic needs of food, shelter, and security, the objectives of societies are not only diverse but stunningly arbitrary. By coincidence I spoke of this phenomenon just over a year ago at an OECD conference on innovation in Oslo: "The innovations of interest to us here are those that become integrated into economies. What causes them to be adopted depends on their ability to satisfy some perceived need by consumers, and that perception may be an artifact of marketing, or fashion, or cultural inertia, or ignorance. Some of the largest and most profitable industries in the developed world – entertainment, automobiles, clothing and fashion accessories, health products, children's toys, grownups' toys! – depend on perceptions of need that go far beyond the utilitarian and are notoriously difficult to predict. And yet these industries clearly depend on sophisticated and rapidly advancing technologies to compete in the marketplace. Of course they do not depend *only* upon technology. Technologies are part of the environment for innovation, or in a popular and very appropriate metaphor – part of the *innovation ecology*." (The speech is attached.)

This ambiguity of perceived need is a deep and largely unrecognized problem for innovation policy, and is an Achilles heel of policy approaches that attempt to match programs to outcomes. Policy outcomes are difficult to measure even under ideal conditions. The possibility of deciding whether they are desirable outcomes cannot be taken for granted. The perception of need and the assignment of value to outcome alternatives are science and innovation policy problem areas that need much more scholarly attention than they have received.

OECD "HIGH LEVEL MEETING OF THE COMMITTEE FOR SCIENTIFIC AND TECHNOLOGICAL POLICY"

OSLO, Norway
March 4, 2008

KEYNOTE ADDRESS: "ADJUSTING POLICY TO NEW DIMENSIONS IN SCIENCE, TECHNOLOGY AND INNOVATION"

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I have been asked to speak this morning on a set of topics whose main characteristics are complexity and breadth, so you will not be surprised to hear me say that the greatest danger in "adjusting policy to new dimensions in science, technology and innovation" lies in over-simplification and one-size-fits-all policy principles. Having said that, I will now endeavor to identify some over-simplified principles that could be used to guide policy adjustments. Let me begin with a few general remarks to prepare the way.

First of all, linking the words 'science,' 'technology,' and 'innovation,' may suggest that we know more about how these activities are related than we really do. This very common linkage implicitly conveys a linear progression from scientific research to technology creation to innovative products. More nuanced pictures of these complex activities break them down into components that interact with each other in a multi-dimensional socio-technological-economic network. A few examples will help to make this clear.

Science has always functioned on two levels that we may describe as curiosity-driven and need-driven, and they interact in sometimes surprising ways. Galileo's telescope, the paradigmatic instrument of discovery in pure science, emerged from an entirely pragmatic tradition of lens-making for eye-glasses. And we should keep in mind that the industrial revolution gave more to science than it received, at least until the last half of the nineteenth century when the sciences of chemistry and electricity began to produce serious economic payoffs. The flowering of science during the era we call the enlightenment owed much to its links with crafts and industry, but as it gained momentum science created its own need for practical improvements. After all, the frontiers of science are defined by the capabilities of instrumentation, that is, of technology. The needs of pure science are a huge but poorly understood stimulus for technologies that have the capacity to be disruptive precisely because these needs do not arise from the marketplace. The innovators who built the world wide web on the foundation of the Internet were particle physicists at CERN, struggling to satisfy their unique need to share complex information. Others soon discovered "needs" of which they had been unaware that could be satisfied by this innovation, and from that point the Web transformed the Internet from a tool for the technological elite into a broad platform for a new kind of economy.

Necessity is said to be the mother of invention, but in all human societies "necessity" is a mix of culturally conditioned perceptions and the actual physical necessities of life. The concept of need, of what is wanted, is the ultimate driver of markets and an essential dimension of innovation. And as the example of the world wide web shows, need is very difficult to identify before it reveals itself in a mass movement. Why did I not know I needed a cell phone before nearly everyone else had one? Because until many others had one I did not, in fact, need one. Innovation has this chicken-and-egg quality that makes it extremely hard to analyze. We all know of visionaries who conceive of a society totally transformed by their invention, and who are bitter that the world has not embraced their idea. Sometimes we think of them as crackpots, or simply unrealistic about what it takes to change the world. We practical people necessarily view the world through the filter of what exists, and fail to anticipate disruptive change. Nearly always we are surprised by the rapid acceptance of a transformative idea. If we truly want to encourage innovation through government policies, we are going to have to come to grips with this deep unpredictability of the mass acceptance of a new concept. Works analyzing this phenomenon are widely popular under titles like "*The Tipping Point*" by Malcolm Gladwell or more recently the book by N.N. Taleb called "*The Black Swan*," among others.

The innovations of interest to us here are those that become integrated into economies. What causes them to be adopted depends on their ability to satisfy some perceived need by consumers, and that perception may be an artifact of marketing, or fashion, or cultural inertia, or ignorance. Some of the largest and most profitable industries in the developed world – entertainment, automobiles, clothing and fashion accessories, health products, children's toys, grownups' toys! – depend on perceptions of need that go far beyond the utilitarian and are notoriously difficult to predict. And yet these industries clearly depend on sophisticated and rapidly advancing technologies to compete in the marketplace. Of course they do not depend only upon technology. Technologies are part of the environment for innovation, or in a popular and very appropriate metaphor – part of the *innovation ecology*.

This complexity of innovation and its ecology is conveyed in Chapter One of a currently popular best-seller in the U.S. called "*Innovation Nation*" by the American innovation guru, John Kao, a formerly on the faculty of the Harvard Business School:

> "I define it [innovation]," writes Kao, "as the ability of individuals, companies, and entire nations to continuously create their desired future. Innovation depends on harvesting knowledge from a range of disciplines besides science and technology, among them design, social science, and the arts. And it is exemplified by more than just products; services, experiences, and processes can be innovative as well. The work of entrepreneurs, scientists, and software geeks alike contributes to innovation. It is also about the middlemen who know how to realize value from ideas. Innovation flows from shifts in mind-set that can generate new business models, recognize new opportunities, and weave innovations throughout the fabric of society. It is about new ways of doing and seeing things as much as it is about the breakthrough idea."

This is not your standard OECD-type definition. Gurus, of course, do not have to worry about leading indicators and predictive measures of policy success. Nevertheless some policy guidance can be drawn from this high level "definition," and I will do so later.

The first point, then, is that the structural aspects of "science, technology, and innovation" are imperfectly defined, complex, and poorly understood. There is still much work to do to identify measures, develop models, and test them against actual experience before we can say we really know what it takes to foster innovation. The second point I want to make is about the temporal aspects: all three of these complex activities are changing with time. Science of course always changes through the accumulation of knowledge, but it also changes through revolutions in its theoretical structure, through its ever-improving technology, and through its evolving sociology. The technology and sociology of science are currently impacted by a rapidly changing information technology. Technology today flows increasingly from research laboratories but the influence of technology on both science and innovation depends strongly on its *commercial* adoption, that is, on market forces. Commercial scale manufacturing drives down the costs of technology so it can be exploited in an ever broadening range of applications. The mass market for precision electro-mechanical devices like cameras, printers, and disk drives is the basis for new scientific instrumentation and also for further generations of products that integrate hundreds of existing components in new devices and business models like the Apple iPod and video games, not to mention improvements in old products like cars and telephones. Innovation is changing too as it expands its scope beyond individual products to include all or parts of systems such as supply chains, and inventory control, as in the Wal-Mart phenomenon. Apple's iPod does not stand alone; it is integrated with iTunes software and novel arrangements with media providers.

With one exception, however, technology changes more slowly than it appears because we encounter basic technology platforms in a wide variety of relatively short-lived products. Technology is like a language that innovators use to express concepts in the form of products and business models that serve (and sometimes create) a variety of needs, some of which fluctuate with fashion. The exception to the illusion of rapid technology change is the pace of information technology, which is no illusion. It has fulfilled Moore's Law for more than half a century, and it is a remarkable historical anomaly arising from the systematic exploitation of the understanding of the behavior of microscopic matter following the discovery of quantum mechanics. The pace would be much less without a continually evolving market for the succession of smaller, higher capacity products. It is not at all clear that the market demand will continue to support the increasingly expensive investment in fabrication equipment for each new step up the exponential curve of Moore's Law. The science is probably available to allow many more capacity doublings if markets can sustain them. Let me digress briefly on this point.

Many science commentators have described the twentieth century as the century of physics, and the twenty-first as the century of biology. We now know that is misleading. It is true that our struggle to understand the ultimate constituents of matter has now encompassed (apparently) everything of human scale and relevance, and that the universe of biological phenomena now lies open for systematic investigation and dramatic applications in health, agriculture, and energy production. But there are two additional frontiers of physical science, one already highly productive, the other very intriguing. The first is the *frontier of complexity*, where physics, chemistry, materials science, biology, and mathematics all come together. This is where nanotechnology and biotechnology reside. These are huge fields that form the core of basic science policy in most developed nations. The basic science of the twenty-first century is neither biology nor physics, but an interdisciplinary mix of these and other traditional fields. Continued development of this domain contributes to information technology and much else. I mentioned two frontiers. The other physical science frontier borders the nearly unexploited domain of *quantum coherence phenomena*. It is a very large domain and potentially a source of entirely new platform technologies not unlike microelectronics. To say more about this would take me too far from our topic. The point is that nature has many undeveloped physical phenomena to enrich the ecology of innovation and keep us marching along the curve of Moore's Law if we can afford to do so.

I worry about the psychological impact of the rapid advance of information technology. I believe it has created unrealistic expectations about all technologies, and has encouraged a casual attitude among policy makers toward the capability of science and technology to deliver solutions to difficult social problems. This is certainly true of what may be the greatest technical challenge of all time – the delivery of energy to large developed and developing populations without adding greenhouse gases to the atmosphere. The challenge of sustainable energy technology is much more difficult than many people currently seem to appreciate. I am afraid that time will make this clear.

Structural complexities and the intrinsic dynamism of science and technology pose challenges to policy makers, but they seem almost manageable compared to the challenges posed by extrinsic forces. Among these are globalization and the impact of global economic development on the environment. The latter, expressed quite generally through the concept of "sustainability" is likely to be a component of much twenty-first century innovation policy. Measures of development, competitiveness, and innovation need to include sustainability dimensions to be realistic over the long run. Development policies that destroy economically important environmental systems, contribute to harmful global change, and undermine the natural resource basis of the economy are bad policies. Sustainability is now an international issue because the scale of development and the globalization of economies have environmental and natural resource implications that transcend national borders.

From the policy point of view globalization is a not a new phenomenon. Science has been globalized for centuries and we ought to be studying it more closely as a model for effective responses to the globalization of our economies. What is striking about science is the strong imperative to share ideas through every conceivable channel to the widest possible audience. If you had to name one chief characteristic of science it would be empiricism. If you had to name two, the other would be open communication of data and ideas. The power of open communication in science cannot be overestimated. It has established, uniquely among human endeavors, an absolute global standard. And it effectively recruits talent from every part of the globe to labor at the science frontiers. The result has been an extraordinary legacy of understanding of the phenomena that shape our existence. Science is the ultimate example of an open innovation system.

Science practice has received much attention from philosophers, social scientists, and historians during the past half-century, and some of what has been learned holds valuable lessons for policy-makers. It is fascinating to me how quickly countries that provide avenues to advanced education are able to participate in world science. The barriers to a small but productive scientific activity appear to be quite low and whether or not a country participates in science appears to be discretionary. A small scientific establishment, however, will not have significant direct economic impact. Its value at early stages of development is indirect, bringing higher performance standards, international recognition, and peer role models for a wider population. A science program of any size is also a link to the rich intellectual resources of the world scientific community. The indirect benefit of scientific research to a developing country far exceeds its direct benefit, and policy needs to recognize this. It is counterproductive to base support for science in such countries on a hoped-for direct economic stimulus.

Keeping in mind that the innovation ecology includes far more than science and technology, it should be obvious that within a small national economy innovation can thrive on a very small indigenous science and technology base. But innovators, like scientists, do require access to technical information and ideas. Consequently, policies favorable to innovation will create access to education and encourage free communication with the world technical community. Anything that encourages awareness of the marketplace and all its actors on every scale will encourage innovation.

This brings me back to John Kao's definition of innovation. His vision of "the ability of individuals, companies, and entire nations to continuously create their desired future" implies conditions that create that ability, including most importantly educational opportunity. The notion that "innovation depends on harvesting knowledge from a range of disciplines besides science and technology" implies that innovators must know enough to recognize useful knowledge when they see it, and that they have access to knowledge sources across a spectrum that ranges from news media and the internet to technical and trade conferences. If innovation truly "flows from shifts in mind-set that can generate new business models, recognize new opportunities, and weave innovations throughout the fabric of society," then the fabric of society must be somewhat loose-knit to accommodate the new ideas. Innovation is about risk and change, and deep forces in every society resist both of these. A striking feature of the U.S. innovation ecology is the positive attitude toward failure, an attitude that encourages risk-taking and entrepreneurship.

All this gives us some insight into what policies we need to encourage innovation. Innovation policy is broader than science and technology policy, but the latter must be consistent with the former to produce a healthy innovation ecology. Innovation requires a predictable social structure, an open marketplace, and a business culture amenable to risk and change. It certainly requires an educational infrastructure that produces people with a global awareness and sufficient technical literacy to harvest the fruits of current technology. What innovation does not require is the creation by governments of a system that defines, regulates, or even rewards innovation except through the marketplace or in response to evident success. Some regulation of new products and new ideas is required to protect public health and environmental quality, but innovation needs lots of freedom. Innovative ideas that do not work out should be allowed to die so the innovation community can learn from the experience and replace the failed attempt with something better.

Do we understand innovation well enough to develop policy for it? If the policy addresses very general infrastructure issues such as education, economic and political stability and the like, the answer is perhaps. If we want to measure the impact of specific programs on innovation, the answer is no. Studies of innovation are at an early stage where anecdotal information and case studies, similar to John Kao's book – or the books on Business Week's top ten list of innovation titles – are probably the most useful tools for policy makers.

I have been urging increased attention to what I call the science of science policy – the systematic quantitative study of the subset of our economy called science and technology – including the construction and validation of micro- and macro-economic models for S&T activity. OECD has been a valuable player in this enterprise, and can do much by its example to encourage deeper knowledge of the innovation ecology and thus provide better tools for policy makers. The deep effort OECD is now making to gather information about innovation is a welcome and valuable enterprise that must continue over a long period of time to be successful. Meetings such as this one are useful and necessary, but by no means sufficient. Innovators themselves, and those who finance them, need to identify their needs and the impediments they face. Eventually we may learn enough to create reliable indicators by which we can judge the health of our innovation ecosystems. The goal is well worth the sustained effort that will be required to achieve it.

RECONCILING THE SUPPLY OF AND DEMAND FOR RESEARCH IN THE SCIENCE OF SCIENCE AND INNOVATION POLICY

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If a tree falls in the forest and no one is there to hear it, does it make a sound? This centuries old philosophical riddle attributed to George Berkeley (1710/1957) suggests that if no one perceives a sound, the sound does not exist. One could extend this thinking metaphorically with the fallen tree serving as knowledge that goes unused i.e., the results of research that are never found and, therefore, never made actionable. Is content really content if it goes unused? Science policy research may exist or may be stored in repositories, but if it is not accessible, not found, seldom read and not applied, it may as well not exist at all.

What can scholars who study science and innovation policy do to contribute more effectively to the information and knowledge needs of decision makers? They could make their research papers, models, databases and other content easily findable, accessible and usable. The traditional model for the dissemination of scholarly research is submission of scholarly papers to peer reviewed publications where hard copy is bound in journal format and possibly posted in abstract form to the journal's website or included in a proprietary database available only through subscription. Randy Shilts, the investigative journalist, recounted the tragedy of allowing current and vitally needed medical research on HIV/AIDS to be relegated to the legacy medical journals where publication was delayed (2000). The science that could have saved thousands of lives lost to AIDS languished in the hands of journal reviewers and remained unrevealed and, therefore, unused during the height of the epidemic. There were political factors at work in the HIV/AIDS controversy in the 1970s and 1980s as well, but the delay in publication of the medical science research was a clear case of hidden knowledge.

What does it mean for scholars to make their science research more findable, accessible, and usable? First, it would mean that results of science research would be made available on open websites. The movement toward university web-based repositories would be one option; personal faculty websites with links to full text articles would be another. Open source repositories in academic libraries offer continual preservation of digital objects that have persistent value. With professional cataloguers doing the tagging, libraries offer the best type of access points for all who wish to find and use the science research. The open repository model also offers economic advantages for libraries since the price of scientific journals, some with subscriptions costing thousands annually, has become unsustainable (Crane, 2007). The scope of influence for faculty members would be expanded considerably because their work would be found, used and cited.

The repository model has an intellectual advantage. The new digital libraries being built by academic libraries that contain science research allow new study methods named 'cyberscholarship" – data analysis and manipulation made possible by using digital data repositories. The US National Institute of Health has developed tools that allow for data-driven science by the mining and analysis of huge stores of data that would be impossible to examine manually (Arms, 2007). Online networks also make available new types of scholarly social networking where data can be shared freely, such as through the scholarly science archive at Cornell University arXiv.org (http://arxiv.org/), the Internet Archive (http://www.archive.org/index.php), and the Rutgers University protein database (http://www.rcsb.org/pdb/home/home.do).

The biggest advantage of an open source, freely accessible platform is the impact a scholars' research can have when published through an online infrastructure. In a large sample of 4,633 scholarly papers on ecology, applied mathematics, sociology, and economics, 49% were published on open access websites and 51% were available only through toll (or purchased) access. The open access articles were cited an average of 9.04 times, whereas the for-pay articles were cited 5.76 times (Norris, Oppenheim & Rowland, 2008). These results are concordant with other studies that show that when research is easy to find, scholars will use it. There is reason to believe that policy makers and other decision makers would use findable research on the Web to add to their knowledge base as well.

For a variety of reasons the repository movement has not established itself in a significant intellectual way. Efforts have not reached a critical mass, and "champions" of the movement have not clearly articulated the advantages of open source digital libraries or repositories. Academic librarians could take on this role, but up until now, they have been promoting repositories primarily among themselves at library conferences and in library journals. Acceptance of open source publication by tenure and promotion committees as evidence of quality scholarship would also go a long way in making digital repositories the publication method of choice.

In the new "culture of contribution" made possible by Web 2.0 and digital content management system (Borgman, 2008), science may seem more plentiful than it did in the print paradigm because the supply will be visible and usable. If science research is not findable and visible, then the supply will never meet the demand. Instead of tolerating fallen trees in the forest, scholars can use open source platforms and can also advocate for innovative use of digital archives. It is evident that more open source archiving will be beneficial to knowledge seekers and knowledge producers, as well as those making science policy decisions.

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WHAT DO SCIENCE POLICY DECISION-MAKERS NEED TO KNOW ABOUT HOW TO MAKE SCIENTIFIC INFORMATION MORE USEFUL FOR POLICY?

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The RISA research was conducted as part of the University of Colorado's "Science Policy Assessment and Research on Climate" grant that was funded by the National Science Foundation, with PIs Roger Pielke Jr., Lisa Dilling and Dan Sarewitz. Research in Indonesia was conducted under an NSF grant "Boundary Organizations for Integrating Knowledge and Action in Sustainable Development" at Harvard University's Sustainability Science Program with PIs Bill Clark, Meine van Noordwijk, Dave Guston and Nancy Dickson.

The following essay draws heavily from existing work, including:

> McNie, Elizabeth C. 2008. "Co-producing useful climate science for policy: lessons from the RISA program". PhD Dissertation, University of Colorado, Boulder.
>
> McNie, Elizabeth C., Meine van Noordwijk, William C. Clark, Nancy M. Dickson, Niken Sakuntaladewi, Suyanto, Laxman Joshi, Beria Leimona, Kurniatun Hairiah, and Noviana Khususiyah. "Boundary Organizations, Objects, and Agents: Linking Knowledge with Action in Agroforestry Watersheds." Report of workshop held in Batu, Malang, East Java, Indonesia – 26-29 July 2007. CID Graduate Student and Research Fellow Working Paper No. 34, Center for International Development at Harvard University, Cambridge, MA, and World Agroforestry Centre – ICRAF Working Paper No 80, World Agroforestry Centre, Nairobi, Kenya. Dec., 2008.

One of biggest challenges in bringing scientific information to bear in policy decisions – whether by elected officials or by individuals or groups of stakeholders – involves designing and implementing the processes and mechanisms that can overcome the inherently weak linkages between science and society in order clarify choices, expand alternatives and otherwise improve decision-making. Whether we call such processes 'reconciling supply and demand' or 'linking knowledge with action', the challenges remain the same: producing useful information that is considered salient, credible and legitimate by the users, and providing support so that information is actually used. Such challenges are particularly true in problems that involve complex, coupled human-environmental systems such as adaptation to climate change and ecosystem management. In the following pages I describe two research projects that examined the processes of reconciling supply of and demand for climate science information for decision makers in the United States, and of linking knowledge with action through the efforts of a boundary organization engaged in creating rewards for ecosystem services through improved agroforestry practices in Indonesia. Both cases share success in producing useful information for decision makers and thus offer insight into those practices that support science for policy (the production of policy-relevant and useful research to improve decisions), but also policy for science (decisions about what science to conduct and how to support it).

Case I: Regional Integrated Sciences and Assessments Program of the National Oceanic and Atmospheric Administration

The RISA program was created with the intent of producing usable climate science, sustainable decision support, and place-based integrated climate sciences (see. http://www.climate.noaa.gov/cpo-pa/risa/). There are eight different RISA programs in the United States and each has its own regional area and focuses on specific climate adaptation issues spanning such topics such as agriculture, natural hazards, forestry, public health, water management, hydropower production, and others. RISAs provide primarily short-term climate information modulated largely by El Niño and La Niña events. Each program also designs its own engagement mechanisms to connect science with decision-makers, thus offering a fertile ground by which to examine how such work was done. My research focused on three RISA programs, the Climate Impacts Group, The Pacific RISA, and Climate Assessment of the Southwest.

The research findings indicated that problem-oriented or use-inspired research conducted by the RISA programs did lead to the production of useful information that was used and that lead to improved decisions among stakeholders. Several factors emerged as key practices in supporting the co-production of useful information, as follows:

- Creation and maintenance of social capital: social capital was essential to communicate across cultures (e.g. science and society), mediate across boundaries, and build mutually respectful relationships based on trust. The social capital played a critical role in the collaborative production of useful information that must not only be context-sensitive, but also credible (of high quality) and legitimate, in that users believe the information was produced with their best interest in mind. Tending to relationships between and among stakeholders is time consuming but also critical to so many aspects of the work the RISAs accomplished. Relationships not only enabled the RISAs to clarify the specific problems their stakeholders needed resolving, but also facilitated the adoption and integration of the information by the stakeholders. In this sense, attention must be paid to both the information product as well as the process of collaboratively producing the information.

- Communication: In order to ensure that useful information is produced and integrated into stakeholders' decision-making processes, RISA personnel communicated early, iteratively and frequently with stakeholders. Moreover, communication and information flowed in both directions: from the RISAs to the stakeholders, and back to the RISAs. The programs utilized a variety of mechanisms to communicate with stakeholders including both formal and informal communication mechanisms such as surveys, focus groups, workshops, direct personal communication, and others. Communication continued even after delivery of products including the use of various evaluation instruments.

- Organizational Design: organizationally speaking, the RISAs tended to embrace an entrepreneurial approach to work, remaining flexible, nimble and adaptable to the limitations of resources and responsive to the emergence of new opportunities for enhancing linkages with stakeholders. Flexibility and adaptation, coupled with clear and well-defined missions and visions for success guided each RISA program's decisions about their own research agendas, ensuring a greater degree of relevance to the problem at hand. A rather decentralized hierarchy and management approach also supported the entrepreneurial approach used by the RISAs. The various RISA programs also shared several leadership characteristics, in that they were lead by individuals who championed the RISA program, supported the professional development and work of the RISA members, and continuously clarified the vision of the program, guiding decisions that supported long-term goals.

- Learning Culture: the organizations fostered and embraced a learning culture in order to share and integrate their own observations into organizational best practices. While these institutions were consistent across the RISAs, the specific approaches used by each RISA differed greatly in order to respond to the particular context each program. RISAs also worked to educate their stakeholders, and to build their capacity to use information and bring such information to bear in decision making.

Case II: Using Boundary Organizations to Link Knowledge with Action in Indonesia Agroforestry Research and Policy

This research sought to determine whether boundary organizations facilitate linking knowledge with action for sustainable agroforestry in Indonesia and to determine how the boundary organizations functioned. Most research on the role of boundary organizations has focused on western/northern contexts and thus does not adequately inform their role in the context of sustainable development characterized by significant power, knowledge, and resource asymmetries more typical in the global south, and thus research sought to evaluate boundary organizations in this context. This research examined a program called Rewarding Upland Poor for Environmental Services (RUPES), a project run by ICRAF (The World Agroforestry Centre - http://www.worldagroforestry.org/sea/networks/rupes/about.htm) that sought to improve both conservation and economic development in agroforestry landscapes. RUPES's work involved multiple decision makers at multiple scales (from individuals and village leaders to national decision makers), from both public and private sectors, and from various geographical and cultural locations around Indonesia. RUPES established mechanisms to pay or reward farmers for environmental services related to water conservation, soil conservation, biodiversity, reduced illegal logging, and conservation. While many of the reward for environmental services have yet to be institutionalized completely, RUPES did succeed in providing useful information in order to implement many of the aforementioned environmental services. Key considerations for such success include the following:

- Problem-oriented research: RUPES paid particular attention to identify the full context of specific problems in order to provide information deemed useful by users. RUPES used multiple mechanisms to clarify the problems, including formal scientific assessments, participatory research, surveys and focus groups, and analysis of physical, human and social capital. In some cases, what stakeholders thought were politically-based problems were actually better addressed through science, and at times the opposite was true. RUPES spent enough time, however, with stakeholders to clarify the problem in order to ascertain a deeper, and hence more accurate, understanding of the problems on which they worked.

- Integrating Research: RUPES supported participation of stakeholders in research as much as possible. A large part of the integration process also involved capacity building for stakeholders so they could integrate, utilize, and even add to the information RUPES provided. In this regard, RUPES created and fostered a culture of learning among stakeholders, not only on issues relevant to the RUPES program, but on other issues deemed important by its stakeholders if RUPES believed such effort supported long term interests. Morever, RUPES paid significant attention to local, indigenous and political knowledge and integrate all knowledge together in order to reflect the full context of the problem at hand.

- Negotiation Support: creating rewards for environmental services requires a great deal of effort to clarify and codify goods and services, and RUPES provided significant negotiation support and mediation across numerous boundaries to support such efforts. This support consisted of providing key scientific information to resolve disputes, or providing an objective and trusted voice in dispute resolution or the negotiation process through which all stakeholders could engage. At times, however, RUPES elevated its own interests and actively pursued them during the negotiations. For example, RUPES actively worked toward establishing certain practices or accounting standards based on their understanding of the scientific and social realities on the ground rather than deferring to stakeholder interests. RUPES believed this to be in the best interest of meeting overall program goals.

- Social Capital and Trust: RUPES worked diligently to create and maintain social capital and trust, factors of considerable importance given the significant power and resource asymmetries in Indonesia. Most of the actual RUPES work was conducted through 'boundary agents', individuals who possessed adequate scientific knowledge and political credibility among stakeholders on different sides of the boundaries. For example, forest extension workers, already well trust by farmers, served as boundary agents in one area. They had some shortcomings in the science but were provided additional training by RUPES to be fluent to both constituents. In another area, trained researchers served as boundary agents. While they possessed the technical knowledge, they lacked the social connections with stakeholders and so were embedded into several villages for six months in order to develop the trust and relationships necessary to do the subsequent work by RUPES.

- Managing the Boundary: As a boundary organization, RUPES actively managed the boundary between and among the multiple stakeholders with whom they worked. Individual 'boundary agents' had very important roles in managing the boundary, communicating among stakeholders and in providing negotiation support. Unlike the western/northern model of boundary organizations, the RUPES organization – the bricks and mortar – mattered little in the work they did. What did matter, however, was the reputation or 'brand identity' that RUPES and ICRAF brought to the work as an international research organization. RUPES and the boundary agents could leverage the embedded trust and legitimacy their reputation had among stakeholders in order to do the work they did.

- Boundary work: in the western/northern experiences of boundary organizations, significant work is done to bring science and society closer together in order to 'bridge the gap' and support the production of useful information. In Indonesia, however, the scientific and political systems were too close and the scientific enterprise too constrained by the political system. Effective boundary work involved creating greater space between those two worlds, rather than bringing them closer.

Many lessons can be gleaned from both the RISA research the boundary organization research in Indonesia that should be considered by science-policy decision-makers, including the following:

- Use-inspired research does not drive out basic research: in both cases, scientists who engaged in problem-oriented research produced useful information that improved policy decisions. The same scientists also discovered new knowledge – fundamental knowledge – about how the world works. Use-inspired research may be very simple, for example in connecting stakeholders to existing knowledge or scaling down information for a specific problem, but it may also require scientists to move the frontier of our knowledge about the world before they can address a specific problem. Room needs to be made for all types of research – use-inspired, basic, applied, etc. – in order to avoid over-privileging basic research at the expense of use-inspired research.

- Develop appropriate metrics and tools for evaluation: evaluating use-inspired research is particularly challenging, and the agencies that fund such research need to take this challenge into consideration when evaluating such programs. Programmatic evaluations need to consider the increased amount of time it takes to create and maintain social capital, develop relationships based on trust, and build capacity among stakeholders to integrate new knowledge. The production of knowledge products is not sufficient to evaluate this kind of work. Reward

- Efforts to reconcile the supply of and demand for useful information requires time: time to accurately ascertain the full extent of the problem, time to build social capital and relationships based on mutual trust and respect, and time to build capacity among stakeholders to actually integrate and use such information in decision making. Patience and persistence are two characteristics necessary for this kind of work.

THE NEED TO DEFINE SUCCESS

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In order to have a useful dialogue on the process of reconciling the supply and demand for science, we must include a discussion on how we define success. Policy scholars, scientists, and decision makers can gauge success at two different levels. On one level we evaluate success in a discrete binary format with two possible outcomes: either the process is successful or unsuccessful. This allows for a basic assessment of whether the process meets the goal of reconciling the supply and demand for science. At an advanced level we can evaluate success on a continuous scale that measures the level of success. This provides a more sophisticated assessment of how well the process reconciles the supply and demand for science. Both levels of evaluation pose the same question of what criteria or metrics should be used to define success. Determining the appropriate criteria and metrics is necessary for framing a detailed goal, planning an effective process, and performing thorough appraisals.

Sarewitz and Pielke Jr. provide a framework for a basic appraisal of the process for reconciling supply and demand for science. They evaluate the process based on judging "how … research opportunities and patterns of information production match up with demand side information needs, capabilities, and patterns of information use." (Sarewitz & Pielke Jr., 2007)

They suggest doing this by assessing the extent of the information supply through an "analysis of documents describing research activities of relevant organizations, from bibliometric and content analysis of research articles produced by these organizations, and from workshops, focus groups, and interviews. The result would be a taxonomy of suppliers, supply products, and research trajectories." (Sarewitz & Pielke Jr., 2007) This should be compared to the needs declared by policy makers.

Evaluating success with this type of judgment contains one weakness, however. It assigns a normative power to the needs declared by policy makers when those stated needs might actually be inappropriate. Consider the case with the Department of Homeland Security Science and Technology Directorate (DHS S&T). DHS S&T holds a bias in favor of technology development over natural and social science research. Therefore DHS S&T policy makers define their needs for information on product development cycles or technology transfer timeframes. They are receiving the information they think they need but scholars external to DHS S&T suggest they should be requesting information on science research instead, such as hurricane dynamics or bioagent dose responses.

Therefore is the DHS S&T process considered successful or unsuccessful? Knowledge producers are meeting the needs of policy makers but scholars argue that the stated needs are inappropriate. Is this issue beyond the scope of a basic evaluation of success? Should this weakness affect how we gauge success? If so, what else do we need to include in a criteria defining success? Should we more explicitly evaluate the credibility, salience, and legitimacy of the knowledge produced (Cash et al., 2003)? Should we more explicitly assess the capability of science to adapt to institutional contexts as mentioned by Sarewitz and Pielke Jr.? If these nuanced factors should be included as criteria for defining success, we face the challenge of determining metrics to gauge them.

This leads to the question of what metrics we should use to measure success in the process of reconciling supply and demand for science. The answers to this question are important for creating an appropriate evaluative tool. The use of metrics to gauge success also progresses the evaluation to an advanced mode allowing for the level of success to be measured. This was the goal of the federal government when the Office of Management and Budget (OMB) developed the Program Assessment Rating Tool (PART).

The Government Performance and Results Act (GPRA) of 1993 started a new era of government management requiring federal program performance to exhibit accountability, efficacy, and efficiency. The GPRA provided guidance to federal agencies on establishing program goals, creating plans and assessing performance (GPRA). The PART follows closely behind GPRA by formally evaluating federal programs based on a set of metrics. In efforts to improve federal government performance, the PART assesses "program performance including program purpose and design; performance measurement, evaluations, and strategic planning; program management; and program results" (Office of Management and Budget 2009).

Consider the National Oceanic and Atmospheric Administration's (NOAA) Ecosystem Research Program. The Ecosystem Research Program offers an example of a federal program focused on linking science to decision makers. The program purpose states, "The Ecosystem Research Program is designed to address the need for science in support of wise management of ocean and coastal resources" (OMB).

The PART involves a standard scoring rubric for all programs, as seen below:

I. PROGRAM PURPOSE AND DESIGN (20%)

II. STRATEGIC PLANNING (10%)

III. PROGRAM MANAGEMENT (20%)

IV. RESULTS (50%)

For the Ecosystem Research Program, the PART evaluates success by utilizing a number of measures, many of which extend beyond linking knowledge production to its users. However, the metrics that relate to reconciling the supply and demand for science are listed below according to the category they are listed within along with their weighted significance.

I. PROGRAM PURPOSE AND DESIGN (20%)

- Is the program design effectively targeted so that resources will address the program's purpose directly and will reach intended beneficiaries?

Weight: 20% of Program Purpose and Design

II. STRATEGIC PLANNING (10%)

- Does the program have a limited number of specific long-term performance measures that focus on outcomes and meaningfully reflect the purpose of the program?

Weight: 10% of Strategic Planning

- Does the program have a limited number of specific annual performance measures that can demonstrate progress toward achieving the program's long-term goals?

Weight: 10% of Strategic Planning

- Does the program have baselines and ambitious targets for its annual measures?

Weight: 10% of Strategic Planning

The reference to 'measures' in this category refers to a number of performance measures developed for the program's criteria for success. The measures of relevance to reconciling the supply and demand for science are listed below:

1. Return on investment from the discovery and application of new sustainable coastal, ocean, and Great Lakes products.
2. Percent of U.S. Large Marine Ecosystems with science-based warning systems that decrease human health risks.
3. Cumulative number of coastal, marine, and Great Lakes ecosystem sites adequately characterized for management.

4. Percentage of tools, technologies, and information services that are used by NOAA partners/customers to improve ecosystem-based management.

5. Cumulative number of coastal, marine, and Great Lakes issue-based forecast capabilities developed and used for management.

6. Percent of U.S. Large Marine Ecosystems with integrated environmental and socioeconomic predictive models that address the priority information needs identified by regional managers.

III. PROGRAM MANAGEMENT (20%)

- Are Federal managers and program partners (including grantees, sub-grantees, contractors, cost-sharing partners, and other government partners) held accountable for cost, schedule and performance results?

Weight: 9% of Program Management

IV. RESULTS (50%)

- Has the program demonstrated adequate progress in achieving its long-term performance goals?

Weight: 20% of Results

- Has the program demonstrated adequate progress in achieving its annual performance goals?

Weight: 20% of Results

The PART for the Ecosystem Research Program uses metrics relying heavily on measures of output to gauge success for its process of reconciling the supply and demand for science. There are several advantages of using metrics as the PART does. By quantifying the evaluation, metrics use weighted balances which reflect the varying significance of factors. Metrics also provide a tool for consistency and for clear and directed assessments which ultimately allow for ongoing improvements to the program. The disadvantage of using metrics concerns the inevitable arbitrary assignment of weight to certain factors. In addition, quantifying elusive factors often results in a loss of those characteristics which do not translate well into numbers.

Perhaps the way in which we gauge success for the process of reconciling supply and demand for science should lie somewhere in between a basic evaluation and a PART evaluation. Defining success should involve criteria beyond a basic assessment of whether user needs are met. While the criteria for success does not need quantifiable metrics in the manner that the PART uses, success should be defined with specific performance measures. Directed measures should be coupled with a loose assignment of weight to express the significance of factors in a clear manner.

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RESPONSE PAPER

FOR THE RECONCILING THE SUPPLY OF AND DEMAND FOR RESEARCH IN THE SCIENCE OF SCIENCE AND INNOVATION POLICY WORKSHOP, OSLO, NORWAY

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In their article, Sarewitz and Pielke argue that an important component of ensuring that the "supply" of knowledge is properly oriented towards the "demand" of social problems is to engage in mapping, or assessments, of both the supply and demand sides of the science policy equation. These assessments, they argue, should include analyses of the research environment, providing both a summary of published literature and a "taxonomy" of the actors and institutions involved. Implicit in Sarewitz and Pielke's analysis is the fact that the supply and demand sides of science policy are often oriented in rather different directions. Indeed, while these two sides may often appear to be focused on the same general problem, a more detailed analysis of the social, political, and rhetorical dynamics of a particular policy arena often reveal that suppliers and users are often framing the problem in very different ways, and have different goals. Thus, one of the important steps towards developing better and more effective science and innovation policy is communication between the supply and demand sides of the equation to encourage labor towards the same, or at least similar, goals. This kind of consensus-building may lead to important changes, in particular, changing our understandings of what constitutes supply and demand to solve a particular science policy problem. In the remainder of this response paper, I suggest three ways in which scholars can help to encourage this reflection and reorientation process. In particular, I argue that scholars can: 1) demonstrate how social problems have often been defined in scientific terms, and help us understand how rethinking problems in social terms might alter the role of science and the definition of supply; 2) facilitate the development of inter- or multi-disciplinary approaches to solving social problems; and 3) develop better ways for us to include members of the public in these decision-making processes.

I. FRAMING THE PROBLEM

Analysts have a very important role to play in unraveling how the supply and demand sides of the equation each define policy problems and facilitating consensus-building towards similar problem definition between all of the actors in a particular science policy environment. Historically, the scientific community has had considerable influence in defining how social problems are studied (particularly when they are related to science), while the users of knowledge have had little opportunity to articulate their needs or communicate them to policymakers. Problem definition by the scientific community has led us to address social problems through the lens of the scientific paradigm of the moment, rather than thinking in more broad terms about the kinds of knowledge that needs to be gathered in order to solve a given problem. In sum, our social problems are usually interpreted as scientific problems. Cancer, for example, has been defined primarily in biomedical terms, and oriented towards finding a cure for the disease (Clarke et al. 2003). The vast majority of the National Cancer Institute's (NCI) budget is devoted to molecular biology, biochemistry, and genetics research, while the funds devoted to "cancer prevention and control," for example, is small and getting smaller (Gaughan 2003). Consider, for example, how the cancer problem might be defined differently by the African American community, which has the highest death rate and shortest survival of any racial and ethnic group in the US for most cancers. According to the American Cancer Society, "The causes of these inequalities are complex and are thought to reflect social and economic disparities more than biologic differences associated with race" (American Cancer Society 2009). For this community, the problem is often one of lack of access to services rather than cells gone awry. How might our definition of "supply" change if cancer is defined as a social, environmental, or infrastructural problem, rather than a biomedical one? The case of stem cell research is even more peculiar. Over the last 10-15 years, we have focused almost entirely on the supply side, with only a vague sense of demand. Stem cell research will "cure disease," we are told. But which ones, exactly? When? How much will these therapies cost? What is the likelihood that stem cell interventions will ameliorate disease? The answers to these questions remain mysteries as the scientific problem itself has become the social problem. Here, the problem has been defined almost entirely in supply terms, with the demand side being constructed by the understanding of supply. Stem cell research policy is seen as the problem at hand, rather than spinal cord injury or diabetes, for example. Again, as in the case of cancer, if the users of knowledge played a greater role in the definition of the problem, it would likely be framed in very different terms and lead to very different definitions of what constitutes supply. Scholars can help us not only understand how our current problem definitions have led to particular demands for scientific information, but also help us predict how changes to our problem definition might alter our priorities for knowledge supply.

II. THE PROMISE OF INTERDISCIPLINARITY

The cases of both cancer and stem cell research demonstrate how suppliers have shaped our definitions of science and innovation policy problems, and of appropriate societal outcomes. Reflections on these dynamics leads us to see almost immediately that if the demand side had more influence on problem definition, that it would lead to more multi- and inter-disciplinary solutions. Changing our view of cancer from a biomedical model to one of prevention or access to services, for example, might include more environmental, urban planning, or sociological research. In the case of stem cell research, a focus on disease amelioration might place stem cell research not only in the context of a variety of types of biomedical research, but also incorporate ergonomic, occupational, or medical device research. It may also extend beyond what we traditionally consider supply. In New York City, for example, a dance company has begun to offer dance classes to Parkinson's Disease patients, which they have found to improve both the psychological and physical suffering of these individuals (Lyden 2008; Sulca 2007). Of course, including this type of intervention in the definition of supply is coupled with a redefinition of the problem beyond biomedical terms and a focus on cures to think in different, sometimes non-scientific ways, about improving the daily lives of these sufferers. Scholars have an important role to play here too. Not only can they articulate the tradeoffs between supply and problem definition, they can also help us develop better ways to work in multi- and inter-disciplinary settings. If we begin to pay more attention to the demand side of science and innovation policy, it is inevitable that we will have to consider suppliers beyond the scientific community. This will require us to develop positive models to facilitate translation across fields that have different interests and standards of excellence.

III. LAY EXPERTISE

Shifting science policy towards greater consideration of the needs of the demand side is also likely to require engagement of individuals and communities outside of traditional scholarly and professional communities. While we may be tempted to characterize many of these users as "laypersons" who lack knowledge and expertise, scholars have already shown that these supposed lay, non-expert voices have great contributions to make to the way we think about science policy problems (Epstein 1996; Wynne 2004). In most cases, however, these groups have been strongly affected by the dominant way of thinking about a science policy problem, so it is difficult for both them and analysts to envision how they may view a problem differently. This makes the tasks of scholars more difficult, to be sure, but not impossible. It may require scholars to be more reflective and vigilant, to try to get beyond the dominant ways of thinking about problems to reach other possible paradigms. This may require in-depth interviewing and focus groups, as well as more efforts to seek out contrarian voices. In the case of cancer, for example, there are many groups who have tried to move beyond NCI's definition of the problem and encourage attention to environmental causation (Klawiter 1999). In the case of stem cell research, disability rights activists have rejected the biomedical paradigm and focused on infrastructural means of dealing with the everyday challenges of living with disease (Generations Ahead 2009). "Laypersons" have a great deal of knowledge to offer science policymakers, and scholars can help ensure that their voices are heard the context of other voices that have traditionally been much more loud and respected than theirs. In addition, incorporation of a broad array of lay voices into the science policy process will not only lead to better science policy, it will also diminish critique of the system. By allowing these individuals to participate as equals, policymakers can avoid charges that they are not taking the public interest adequately into consideration.

In sum, I believe that efforts to map the supply and demand aspects of social problems is extremely important, because it will often reveal important differences in how each side defines the problem at hand. This assessment can then lead to discussion, and hopefully consensus, about how to correctly define social problems and subsequently alleviate them. This process of assessment, discussion, and consensus, can be facilitated in a number of ways. First, it is important to note that the scientific community has historically played a very important role in defining the demand for scientific information and what constitutes supply. An honest, broader assessment of supply and demand is likely to invigorate the demand side of the equation and lead to a reorientation of how both problems and supply are defined. In particular, both social problems and supply are likely to be defined in inter- or multi-disciplinary ways, and scholars have an important role to play in helping us understand how these kinds of collaborations (often between very different fields, sometimes even between scholars and non-scholars) can be fruitful. Also, it is important to seriously consider the role of lay expertise both in terms of problem definition and supply. While the cultural authority and credibility of the scientific community has often inadvertently quieted other forms of expertise in discussions about how to solve social problems, scholars have a unique role to facilitate the inclusion of these communities. Such inclusion can lead to better, and more democratic, policies.

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THE NEGLECTED HEART OF SCIENCE POLICY: RECONCILING SUPPLY OF AND DEMAND FOR SCIENCE

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Abstract

The funding of scientific research is almost always justified in terms of the potential for achieving beneficial societal outcomes. In pursuing a particular societal outcome, how can we know if one research portfolio is better than another? In this paper we conceptualize: (1) science in terms of a "supply" of knowledge and information, (2) societal outcomes in terms of a "demand" function that seeks to apply knowledge and information to achieve specific societal goals, and (3) science policy decision-making as a process aimed at "reconciling" the dynamic relationship between "supply" and "demand." The core of our argument is that "better" science portfolios (that is, portfolios viewed as more likely to advance desired societal outcomes, however defined) would be achieved if science policy decisions reflected knowledge about the supply of science, the demand for science, and the relationship between the two. We provide a general method for pursuing such knowledge, using the specific example of climate change science to illustrate how research on science policy could be organized to support improved decisions about the organization of science itself.

1. Introduction to the problem

Most scientific research, whether funded by public or private moneys, is intended to support, advance, or achieve a goal that is extrinsic to science itself. While some research is not expected by anyone to have a result other than the advance of scientific knowledge, such work is an extremely small portion of the overall science portfolio. Funding for research generally considered to be "basic" by those who perform it is usually justified by the expectation that the results will contribute to a particular desired outcome. For example, much of the research supported by the U.S. National Institutes of Health (NIH) is considered "basic" by medical researchers, in that it explores fundamental phenomena of human biology, but robust public support for NIH is explicitly tied to the expectation (and legislative mandate) that research results should end up improving human health.

In pursuing a particular societal goal or set of goals, how do we know if a given research portfolio is more potentially effective than another portfolio? This question would seem to lie at the heart of science policy, yet it is almost never asked, much less studied systematically. Given the complexity of the science enterprise, of the processes of resource allocation, knowledge creation, and knowledge application, it would be very surprising indeed if the capacity of the existing enterprise to advance desired outcomes could not be significantly improved upon. For example, it is broadly accepted that current global priorities in biomedical research are very poorly aligned with global health priorities, a problem commonly termed the "10/90 problem," in reference to the observation that only about 10 percent of the global biomedical research budget is allocated to diseases accounting for about 90 percent of the worlds' health problems (Global Forum for Health Research, 1999).

Moreover, doing research always begs the question: "what research?" Looking again at biomedicine, scientists and other science policy decision makers heatedly debate the question of how much emphasis should be placed on exploring the molecular genetic origins of disease, versus environmental, behavior, nutritional, cultural, and other origins (Curtis, 2000; Hoffman, 2000)(e.g., compare Curtis, 2000 with Hoffman, 2000). Similar tensions flare up in debates over the appropriate balance between treatment (e.g., drugs) and prevention (e.g., vaccinations). Genetics and treatment often win out, not necessarily because they are known to be the best routes to advancing human health, but because they lie at the confluence of advanced technology, high prestige science, market incentives, and even ideology (e.g., genetic determinism; Lewontin, 1993).

Indeed, just "doing research" on a problem of societal importance says nothing directly about whether or under what conditions the research can effectively contribute to addressing that problem (Bozeman and Sarewitz, 2005; Sarewitz et al., 2004). A major commitment to AIDS research starting in the late 1980s led in fairly short time to antiretroviral drugs that are, thus far, quite effective in the treatment of AIDS patients. Yet 90 percent of AIDS sufferers have no reasonable prospect of ever receiving this treatment, largely because they (or the societies in which they live) cannot afford it. The potential for science to contribute to societal goals depends critically on factors well beyond science.

Given how little attention is paid to understanding the relationship between alternative possible research portfolios and stipulated societal outcomes, there is no a priori reason to expect that existing research portfolios are more effective than other possible research portfolios at contributing to the achievement of desired societal outcomes. This being the case, the key question – the neglected heart of science policy – is how one might approach the problem of rigorously assessing the relationship between a research portfolio (or a set of alternative portfolios) and the societal outcomes that the portfolio is supposed to advance.

Some would argue that this problem is inherently intractable. Because the connections between research and societal outcomes cannot be accurately predicted in detail, the argument would go, predicting the differing outcomes of an array of hypothetical or counterfactual research portfolios is impossible. We think such arguments (which are common in science policy debates) are wrong-headed and wrong. Wrongheaded because science policy decisions are constantly being justified on the basis of putative linkages between research investments and desired outcomes. If such justifications cannot be supported analytically or logically, then they should not be asserted in the first place. Wrong because contingency, complexity and non-linearity (i.e., in the relations between science policy decisions and societal outcomes) are obstacles to accurate predictions, but they need not prevent improved decision-making (e.g., Lasswell, 1971; Lindblom, 1959; Sarewitz et al., 2000), where "improved" means more likely to achieve desired outcomes.

Our approach in this paper is to conceptualize science in terms of a "supply" of knowledge and information, societal outcomes in terms of a "demand" function that seeks to apply knowledge and information to achieve specific societal goals, and the relationship between the two as "reconciled," in part, through science policy decision processes. In the next section we develop this conceptualization, drawing briefly from many areas of science policy scholarship. The core of our argument is that "better" science portfolios (that is, portfolios plausibly viewed as more likely to advance desired societal outcomes, however defined) would be achieved if they reflected an understanding of the supply of science, the demand for science, and the complex, dynamic relationship between the two. We will provide a general method for pursuing such knowledge, using the specific example of climate change science to illustrate how research on science policy could be organized to support improved decisions about the organization of science itself.

2. Understanding and mediating the supply of and demand for science in science policy

We borrow from economics the concepts of "supply" and "demand" to discuss the relationship of scientific results and their use for several reasons (cf., Broad, 2002; Dalrymple, 2006). First, the analogy is straightforward. Decisions about science (i.e., science policy decisions) determine the composition and size of research portfolios that "supply" scientific results. People in various institutional and social settings who look to scientific information as an input to their decisions constitute a "demand" function for scientific results. Of course, the demand function can be complicated by many factors, e.g., sometimes a decision maker may not be aware of the existence of useful information or may misuse, or be prevented from using, potentially useful information. In other cases, necessary useful information may not exist or may not be accessible. But our key point is that there is reasonable conceptual clarity in distinguishing between people, institutions, and processes concerned with the supply of science, and those concerned with its use. Indeed, conventional notions of science policy exclusively embody decisions related to the former.

Nonetheless, a second reason for characterizing scientific research in terms of supply and demand is to recognize that, just as in economics, in the case of science supply and demand are closely interrelated. Science policy decisions are not made in a vacuum but with some consideration or promise of societal needs and priorities. Thus there is a feedback between the (perceived) demand for science and the (perceived) characteristics of supply. People with spinal cord injuries or diabetes, influenced by the rhetoric of scientists studying embryonic stem cells, in turn create an enhanced demand for such research. However, whether embryonic stem cell research is itself the "right" path to achieving the desired goals (in this case, presumably cures for the injuries or diseases) is not necessarily apparent. Numerous alternative paths may be available (Garfinkel et al., 2006).

At the same time, we recognize the power and importance of scholarship over the past several decades that reveals the complex manner in which science and society co-evolve, or are co-produced (e.g., Jasanoff, 2004). The insights from such work dictate that categories such as "supply" and "demand" cannot be understood as conceptually discrete or fully coherent. Moreover, both supply of and demand for information emerge from complex networks of individuals and institutions with diverse incentives, capabilities, roles, and cultures. Yet in the face of such complexity, decisions about resource allocation, institutional design, program organization, and information dissemination have been and are still being made. That is, while notions of "supply" and "demand" may embody considerable complexity, they also represent something real and recognizable: on the one hand, people conducting research that has been justified in terms of particular societal outcomes, and on the other, people making decisions aimed at contributing to those outcomes.

Some think the supply function is inherently optimized so long as scientists are freely pursuing knowledge with minimal external interference. This position, most rigorously espoused by Polanyi (1962), views the scientific community as an autonomous, self-regulating market organized to identify and pursue the most efficient lines of knowledge generation. Any "attempt at guiding scientific research toward a purpose other than its own is an attempt to deflect it fromthe advancement of science" (1962, p. 62). From this perspective, the supply of scientific knowledge is best generated without any connection or attention to demand for particular types of knowledge.

The apparent logical and practical weakness of this perspective – that knowledge, efficiently pursued, may or may not be knowledge that has any utility in the world – has been answered in two ways. First, basic knowledge is conceived as accumulating in a metaphorical reservoir from which society can draw to solve its multifarious problems. The reservoir is filled most rapidly and effectively through the advance of science independent of considerations of application. Second, application of basic knowledge to real world problems is often serendipitous, so there is no way to predict the connection between a given line of research and a given social goal. Chemistry (or, one supposes, solid earth geophysics or cosmology) is as likely to help cure a certain disease as is molecular genetics. Numerous anecdotes are offered up to illustrate the significance of serendipity in connecting inquiry to utility (Sarewitz, 1996).

Of course no one really advocates this model in its extreme form. Certainly, if the time scale is long enough (decades and beyond), fundamental advances in knowledge often have broad application beyond anything that could be anticipated, but on the time scales that motivate support for research, strategic investments in basic understanding are invariably conceived in the context of related areas of potential application. This reality has given rise to a weaker version of the science-as-a-self-regulating-market argument, where the need to make strategic investment choices among disciplines and research topics is tacitly acknowledged, but scientists and science advocates still argue that they are best positioned to contribute to social goals if they are given autonomy to pursue knowledge in directions guided by the logic of nature, not the exigencies of social need (Committee on Science Engineering and Public Policy, 1993; Pielke and Byerly, 1998).

The idea that the creation of scientific knowledge is a process largely independent from the application of that knowledge within society has had enormous political value for scientists, because it allows them to make the dual claims that (1) fundamental research divorced from any consideration of application is the most important type of research (Weinberg, 1971) and (2) such research can best contribute to society if it is insulated from such practical considerations, thus ensuring that scientists not only have putative freedom of inquiry, but also that they have control over public resources devoted to science. The continued influence of this perspective was recently asserted by Leshner (2005), Chief Executive Office of the American Association for the Advancement of Science: ". . . historically science and technology have changed society, society nowis likely to want to change science and technology, or at least to help shape their course. For many scientists, any such overlay of values on the conduct of science is anathema to our core principles and our historic success."

Empirical studies of the complex connections between research and societal application give little support to the foregoing conceptions. One of the richest areas of scholarship in this realm has focused on the origins of technological innovation, where case studies and longitudinal surveys have revealed networks of continual feedbacks among a large variety of actors, including academic scientists, industrial scientists, research administrators, corporate executives, policy makers, and consumers. The resulting picture is complex and yields no single, straightforward model for how knowledge and application interact; yet one feature that invariably characterizes successful innovation is ongoing communication between the producers and users of knowledge. Moreover, historical studies of innovation typically show precisely the opposite of what one would expect from the autonomous science argument. Emerging technological frontiers often precede deep knowledge of the underlying fundamental science. It is precisely the demand for better theoretical foundations among those worried about applications that has driven the growth of fundamental science in many areas (e.g., Rosenberg, 1994). As economist Nelson (2004) writes: "for the most part science is valuable as an input to technological change these days because much of scientific research is in fields that are oriented to providing knowledge that is of use in particular areas."

If this seems spectacularly circular, then that is precisely the point: science agendas are closely aligned with areas of technological application because certain areas of science demonstrate themselves to be of particular value to some groups of users. This is a very different view of the world than one in which science advances independently of subsequent applications. Research on the relations between industry and universities, for example, strongly demonstrates that the priorities of academic basic science have long been aligned with the needs of industry (e.g., Crow and Tucker, 2001; Mowery and Rosenberg, 1989). Such alignment is not a result of serendipity, but of the development of networks that allow close and ongoing communication among the multiple sectors involved in technological innovation. Thus, fundamental research relevant to innovation does indeed go on in universities where scientists have considerable autonomy to pursue basic knowledge, but the priorities and directions of this fundamental work are strongly influenced by collaboration with scientists, engineers, and managers working closer to the actual point of product development and application (and they, in turn, are influenced by a variety of end-users or consumers). In the useful term introduced by Stokes (1997), this type of fundamental science is "use-inspired," and it is central to the successful functioning of modern, high technology economies. More generally, the production of knowledge in the broader context of applications has been termed Mode 2 science by Gibbons et al. (1994), to distinguish it from the traditional insistence on "pure" science as the ultimate source of social value.

Two attributes of this discussion bear emphasis. The first is that, in contrast to the canonical portrayal of fundamental science contributing to application because it is free to advance in isolation from consideration of application, studies of technological innovation have often shown exactly the opposite—that it is the awareness of potential application and utility that ensure the contribution of fundamental research to innovation. Second, in contrast to the portrayal of scientific advance as something that is unpredictable and therefore beyond planning or control through influences beyond the scientific enterprise, the history of post-World War II science and technology policy is one of strategic decisions about investments in particular areas of science and engineering in support of specific areas of societal application, such as communications, computing, advanced materials, aviation and avionics, weapons systems, and biotechnology. From the creation of agricultural research stations in the mid 19th century, to the advent of the transistor shortly after World War II, to the continued advance of human biotechnologies today, strategic decisions to focus public sector resources in particular areas of science have consciously and successfully linked research portfolios to technological advance and such societal outcomes as economic growth, agricultural productivity, and military power.

Such outcomes are themselves highly complex, of course. In the past several decades, other lines of scholarship (e.g., Jasanoff et al., 2001) have illuminated how the multifarious societal consequences of scientific and technological advance bear clear evidence of a dynamic relationship between the producers and users of knowledge and innovation, and that this relationship itself is strongly conditioned by broader contextual factors.

For example, the natural, cultural, and political attributes of the United States in the 19th century gave rise to an organization of agricultural science closely tied to the practice of farming and the needs of farmers (and strongly resisted, at first, by scientists seeking to preserve their autonomy), including the development of institutional innovations – the agricultural research station and extension services – to bring supply and demand sides together (e.g. Cash, 2001; Rosenberg, 1997). The inextricable linkages between science, technology, and the geopolitics of the Cold War drove the institutional symbiosis of universities, corporations, and the military that dominated the demand–supply relation in U.S. science for half a century and motivated President Eisenhower's (1960) famous warning about the overweening power of the "military-industrial complex." Feminism and the growing political power of the women's movement in the U.S. eventually led to an understanding that a health research system run by males was often biased toward males in its priorities, practices, and results. Such insights, which were at the time controversial but are now widely accepted, led to significant changes both in the conduct of science and its application in ways that benefit women (e.g., Lerner, 2001; Morgen, 2002). Similarly, the political empowerment arising from the gay rights movement in the U.S. ultimately influenced the course of AIDS research in ways that directly benefited AIDS sufferers in the U.S., for example through more rapid clinical testing and approval of treatments (Epstein, 1996). Based on these successes, "disease lobbies" in the U.S. have become a significant factor in shaping biomedical research priorities.

Such examples illustrate that the supply of science is often responsive to the presence of a well-articulated demand function. Put somewhat more bluntly, scientific research trajectories are often decisively influenced through the application of political pressure by groups with a stake in the outcomes of research and the power and resources necessary to make their voices heard. Obviously, this does not mean that science can produce whatever is asked of it. Moreover, groups lobbying for one type of research or another may or may not actually understand how best to advance their interests. For example, it might be the case that health care delivery reform or changes in behavior would return greater benefits to some disease lobbies than more funding for a particular type of research.

More significantly, there is no reason to think that the influence of particular political interest groups (whether they be disease lobbies or pharmaceutical corporations) on the supply of science will yield outcomes that are broadly beneficial to society; they may, on the contrary, lead to the preferential capture of benefits by certain groups (Bozeman and Sarewitz, 2005). For instance, the very fact that most health research is carried out in affluent societies and responds to the health needs of affluent people has resulted in an increasingly wide gap between science agendas and global health priorities. Scientific opportunities that are likely to yield the greatest return in terms of social benefit (e.g., through vaccine development) are widely neglected. Nonetheless, politics provides a key mechanism for mediating the relationship between – for reconciling – supply of and demand for science via the science policy decision processes that so strongly determine the character of the supply function.

The philosopher Kitcher (2001) has identified an ideal, which he terms "well-ordered science," that describes an optimal relationship between supply and demand (though he does not articulate it using these terms), achieved through an ideal process of representative deliberation:

> For perfectly well-ordered science we require that there be institutions governing the practice of inquiry within society that invariably lead to investigations that coincide in three respects with the judgments of ideal deliberators, representatives of the distribution of [relevant] viewpoints within society. First, at the stage of agenda-setting, the assignment of resources to projects is exactly the one that would be chosen through the process of ideal deliberation. . . Second, in the pursuit of the investigations, the strategies adopted are those which are maximally efficient among the set that accords with the moral constraints the ideal deliberators would collectively choose. Third, in the translation of results of inquiry into applications, the policy followed is just the one that would be recommended by ideal deliberators. . ." (2001, pp. 122–123).

Well-ordered science, like all ideals (democracy, justice, freedom), sets a standard that cannot be met but toward which aspirations can be aimed: science that is maximally responsive to the needs and values of those who may have a stake in the outcomes of the research; the best possible reconciliation of supply and demand. This philosophical ideal adds a normative overlay to what has been demonstrated empirically. Not only are the supply of and demand for science related to each other through a process of politically mediated feedbacks, but in a democracy it is desirable that this feedback process be maximally responsive to the negotiated common interests of relevant stakeholders, rather than captured by particular special interests. Indeed, as Kitcher (2003, p. 218) asserts: "the current neglect of the interests of a vast number of people represents a severe departure from well-ordered science."

Kitcher's notion of "well-ordered science" is procedural; it describes a well-informed process of defining research agendas and practices that reflects the priorities and norms of relevant stakeholders (including, of course, scientists involved in the research). In the real world, intermediary institutions – sometimes called boundary organizations –may enhance the pursuit of well-ordered science by mediating communication between supply and demand functions for particular areas of societal concern (see McNie, this issue, for a comprehensive review). Again, this is not a matter of asking scientists to "cure cancer" or "end war," it is a process of reconciling the capabilities and aspirations of knowledge producers and knowledge users.

Even if the procedural ideal were achieved, it would not guarantee the achievement of a particular stipulated social outcome. Many of the goals of science – curing a given disease, for example – may be difficult to attain for a variety of reasons, ranging from intrinsic scientific difficulty to cultural or institutional complexities. But the key point is that departures from well-ordered science are inherently less likely to achieve such outcomes, because research agendas will not reflect the priorities, needs and capabilities of the broadest group of constituents that could potentially make use of the resulting knowledge and innovation.

3. Supply of and demand for science in decision-making

Our discussion so far has aimed at building a conceptual foundation for assessing the relations between supply of and demand for science as input to the science policy decisions that help reconcile those relations. We have shown: (1) that the notion of supply and demand functions for science helps to clarify the dynamic role of science in society; (2) that supply of and demand for science are reconciled in various ways, with various degrees of success (depending in part on who defines "success"); (3) an ideal reconciliation of supply and demand would match the capabilities of science with the needs of those who could most benefit from it. We now apply these insights to what logically ought to be the most obvious – and tractable – problem of supply–demand relations in science: the use of science to support decision-making in public affairs.

In areas as diverse as national innovation strategies, technological risk, and environmental protection, science is increasingly called upon to provide information that can improve decision-making in public affairs (House Committee on Science, 1998; UNDP, 2001). This growing role for science in part reflects the increasing capacity of scientific methods and tools to study complex systems ranging from genes to climate. But it also reflects the rapidity of societal evolution that results from the increasing power and global reach of science and technology. That is, science is called upon as a tool to monitor and assess the changes that science itself helps to induce (see Beck, 1992). The expectation that science can help inform human decisions about societal change has been especially strong in the area of the environment, and we focus our discussion on the problem of climate change.

Research on decision-making has long recognized that there is no simple connection between "more information" and "better decisions" (Clark and Majone, 1985; Feldman and March, 1981; Sarewitz et al., 2000), and that, to the extent "more information" does not solve a problem, the fault cannot simply be located with the decision maker (i.e., in the demand function). More information may not lead to better decisions for many reasons, e.g., the information is not relevant to user needs; it is not appropriate for the decision context; it is not sufficiently reliable or trusted; it conflicts with users' values or interests; it is unavailable at the time it would be useful; it is poorly communicated. Also, of course, the idea of "better decisions" depends on who stands to benefit from which decisions. Some types of information may support decisions that benefit some people but adversely affect others.

Apparently commonsensical ideas, for example, that climate forecasts would be valuable to people who make decisions related to climate behavior (e.g., water managers, emergency managers, agricultural planners) turn out to be very complex, as such factors as institutional structures, prior practice, socioeconomic conditions, and political stakes and power distributions, strongly influence the types of information that decision makers need and use, and the array of stakeholders that might benefit from such decisions (e.g., Broad, 2002; Lahsen, in press; Lemos et al., 2002; NRC, 1999; Rayner et al., 2002).

Scholars striving to understand the behavior of scientific information in complex decision contexts (especially those related to the environment and sustainability) have converged on the recognition that the utility of information depends on the dynamics of the decision context and its broader social setting (e.g., Jasanoff and Wynne, 1998; Pielke et al., 2000). Utility is not immanent in the knowledge itself. For example, Gibbons (1999) describes the transition from a gold standard of "reliable" knowledge as determined by scientists themselves, to "socially robust" knowledge that, first, "is valid not only inside but also outside the laboratory. Second, this validity is achieved through involving an extended group of experts, including lay 'experts'. And third, because 'society' has participated in its genesis, such knowledge is less likely to be contested than that which is merely reliable" (1999, p. C82).

Arriving at a similar set of insights, Cash et al. (2003) have shown that information capable of improving decisions about the management of complex environmental systems must have the three attributes of credibility, salience, and legitimacy, attributes which can only emerge from close and continual interactions among knowledge producers and users. Pielke et al. (2000) similarly recognized that effective integration of science and decision-making required a tight coupling among research, communication, and use. Guston (1999) pointed to the value of boundary organizations at the interface between science and decision-making for helping to ensure that such integration can occur. Funtowicz and Ravetz (1992) coined the term "post-normal science" to describe the complex organization of knowledge production necessary to address problems of decision-making, in contrast to older notions of autonomous – "normal" – scientific practice.

Despite these conceptual advances – derived, in part, from studying relative successes in such areas as international agricultural research and weather forecasting – the overall picture is neither clear nor encouraging. While the rich world spends billions annually on research aimed at supporting environmental policy, there is not much evidence that significantly enhanced decision-making capabilities or environmental outcomes have resulted (Cash et al., 2003; Lee, 1999; Millennium Ecosystem Assessment, 2005; Sarewitz, 2004). To suggest that "politics" has prevented progress on such issues is merely to restate the problem. Indeed, the recent spate of media and public attention focused on the problem of the "politicization of science" in the U.S. (e.g., Gough, 2003; Mooney, 2005; UCS, 2004) reflects the persistent notion that the contribution of science to decisions is mostly a process of delivering facts to users, and that failure to attend to facts reflects problems in the demand function (i.e., "politics"). This debate is oblivious to the sorts of insights summarized above, which teach us that science is always politicized, and that the real-world challenge is to cultivate an inclusive and nonpathological process of politicization (Pielke, in press; Sarewitz, 2004) that allows a democratically appropriate – wellordered – reconciliation of supply of and demand for information or knowledge. Put somewhat differently, understanding the politics embodied in the supply and demand functions is a key analytical task in support of their improved reconciliation via science policy decisions.

While there are many complex reasons why it is difficult to generate "socially robust knowledge," scholarly attention has focused principally on the dynamics of interactions between knowledge producers and decision makers, and on the need for institutional innovation to enhance such interactions, as briefly summarized above. Very little consideration has been given, however, to science policy—that is, to the decision processes that strongly determine the priorities, institutional settings, and metrics of success for the supply of scientific research (Bozeman and Sarewitz, 2005; Marburger, 2005). Correspondingly, very little consideration has been given to the types of information or knowledge that science policy decision makers could call upon to improve the reconciliation of supply and demand.

The neglect of science policy is especially problematic because the science policy decisions that strongly determine research portfolios, particularly at the macro level, are likely to be made by people, and in institutions, that are distant from the interfaces between research and its potential use. Indeed, the complex interactions among knowledge producers, knowledge users, and intermediaries that characterize postnormal science often takes place within a context of scientific research agendas whose main characteristics have already been determined through science policy decisions. To further complicate matters, the very process of establishing such characteristics helps to empower some potential users (who may benefit from the structure of the supply function) while marginalizing others. These problems are particularly acute for large scale, long-term research efforts, such as global climate change science.

4. Origins of the climate change supply function

In 2003, seven leading U.S. climate scientists wrote (in response to an article by the authors of this paper (Pielke and Sarewitz, 2003)):

> The basic driver in climate science, as in other areas of scientific research, is the pursuit of knowledge and understanding. Furthermore, the desire of climate scientists to reduce uncertainties does not. . . arise primarily from the view that such reductions will be of direct benefit to policy makers. Rather, the quantification of uncertainties over time is important because it measures our level of understanding and the progress made in advancing that understanding (Wigley et al., 2003).

This argument restates the traditional logic for public support of science, discussed at the beginning of our paper: that the exploration of nature, motivated by the desire for understanding, is the best route to beneficial social outcomes. It is consistent with (though more extreme than) the original rationale for the U.S. Global Change Research Program (USGCRP), under whose aegis more than $25 billion were spent on climate research between 1989 and 2003. While the USGCRP was intended by policy makers to provide "useable knowledge" for decision makers, its structure and internal logic reflected the belief that the best route to such useable knowledge was via research motivated predominantly by a desire to expand fundamental understanding. The USGCRP was also motivated by the belief that decision-making would be improved simply by providing additional scientific information (with a particular focus on predictive models) to those making decisions (Pielke, 1995, 1999).

To the extent that the USGCRP's science priorities were responsive to a particular decision context or demand function, this function was the international assessment and negotiation processes aimed at arriving at a global regime for stabilizing greenhouse gas emissions. To the extent that scientists who conduct climate research, and putative users of that science, were interacting, they were doing so mostly as part of the process of developing this regime. The key point here is that the science agenda (i.e., supply function) was linked to an extremely restricted expectation of what sorts of policies would be necessary to deal with climate change (i.e., global policies that governed greenhouse gas emissions), via simplistic but politically powerful notions about what would cause those policies to come about (i.e., increased scientific knowledge about climate change). In this highly restricted, supply-dominated context, the Intergovernmental Panel on Climate Change (IPCC) issued reports throughout the 1990s and early 2000s, written by teams of scientists that assessed the state of expanding knowledge about climate, while the U.S. National Research Council (NRC) issued reports, written by teams of scientists that analyzed research needs and priorities in the context of pursuing a comprehensive understanding of climate behavior. These expert-driven, supply-focused processes were the controlling political influences on the evolution of the climate research agenda (Agrawala, 1998a, b).

The fact that so many billions have been spent on climate research, not just in the U.S. but in other developed countries as well, in turn suggests that there is a demand function which is being served by this research (otherwise, why would policy makers keep spending the money?), although in fact very little is known about the structure and objectives of that demand function. To the extent that the IPCC can be viewed as a sort of boundary organization aimed at connecting the science to its use in society, then this demand function is mostly embodied in the international process for negotiating and implementing climate treaties under the U.N. Framework Convention on Climate Change, especially the Kyoto Protocol. Politicians and policy makers in the U.S. have, over the years, justified their support of the USGCRP largely in terms of the need to have better information before making decisions about climate, where "decisions about climate" has generally meant decisions about emissions reductions under the Framework Convention.

Yet the problem of climate change implicates a much broader array of potential decision makers in the climate change arena than those with a stake in international negotiations (e.g., see Rayner and Malone, 1998; Sarewitz and Pielke, 2000), and would include farmers and foresters, local emergency managers and city planners, public health officials, utility operators and regulators, and insurance companies, among many others. Such constituencies, which define a diverse demand function, have little impact on the evolving agenda for climate research, which has been driven almost exclusively by scientific organizations such as the IPCC and the NRC. In 2003 an exhaustive strategic planning process aimed at refining the USGCRP was dominated by scientific voices plus civil society groups advocating action on the Kyoto Protocol, with little input from actual decision makers who influence, are influenced by, and must respond to, climate change and climate impacts. The resulting Strategic Plan for the U.S. Climate Change Science Program (U.S. Climate Change Science Program, 2003) contains comprehensive recommendations for continuing and expanding climate research, but little information about the needs and capabilities of the potential users of that information (though the report does highlight the importance of such users), and little analysis of how research is actually supposed to benefit various types of users.

Meanwhile, relatively sparse but consistent research conducted under the category of "human dimensions of climate change" (mostly focused on annual to interannual climate variability) has shown that available information on climate is in some cases not deemed useful by decision makers (e.g., Callahan et al., 1999; NRC, 1999; Rayner et al., 2002), in other cases benefits particular users at the expense of others (e.g., Broad, 2002; Lemos et al., 2002), and in yet other cases is misused and contributes to undesired outcomes (e.g., Broad, 2002; Pielke, 1999), and in all cases depends for its value on the types of institutions that are making the decisions (Cash et al., 2003). Overall, however, the institutional structures and feedback processes that lead to increased understanding between supply and demand sectors (characteristic of Mode 2, post-normal, or well-ordered science, and documented as a key element of high technology innovation processes) are largely absent from the climate research enterprise, especially in the United States. *The Potential Consequences of Climate Variability and Change* (National Assessment Synthesis Team, 2001) did encompass a series of regional meetings involving, with various degrees of success, certain stakeholders, but this process has not been institutionalized; rather, it culminated in several reports whose purpose was "to synthesize, evaluate, and report on what we presently know about the potential consequences of climate variability and change for the US in the 21st century." The question of whether "what we presently know" is what we need to know to act effectively was not addressed.

5. Reconciling supply and demand in climate science: a proposed method

The insights derived from several decades of scholarship on the relationship between the production and use of knowledge in many domains of research and application suggest that the organization of climate science in the United States is unlikely to show a strong alignment between the supply of and demands for knowledge among a broad array of potential users. Adopting Kitcher's term, we here hypothesize that climate science is very far from being "well ordered." More importantly, we suggest both that this hypothesis is testable and that, given the scale of public investment and the potential environmental and socioeconomic stakes, the effectiveness of science policies could be greatly enhanced by testing it.

As long ago as 1992, a first (and, as far as we can know, last) step along these lines was taken in the *Joint Climate Project to Address Decision Maker's Uncertainty* (Bernabo, 1992). The project sought to determine "what research can do to assist U.S. decision makers over the coming years and decades," it argued that "[a]n ongoing process of systematic communication between the decision-making and the research communities is essential," and it concluded that "[t]he process started in this project can serve as a foundation and model for the necessary continued efforts to bridge the gap between science and policy" (1992, p. 86).

More than a decade later, the scale of the climate research enterprise, in the U.S. as well as other affluent nations, has increased enormously, along with fundamental understanding of the climate system. At the same time we observe that there is little if any evidence that this growth of understanding can be connected to meaningful progress toward slowing the negative impacts of climate on society and the environment.[1] On the other hand, appreciation of the variety of decision makers and complexity of decision contexts relevant to climate change has greatly deepened. Understanding of this diversity should allow us to ask: what types of knowledge might contribute to decision-making that could improve the societal value of climate science? Next, we outline a methodology of science policy research for assessing and reconciling the supply and demand functions for climate science information.

5.1. Demand side assessment

Research on the human dimensions of climate, though modestly funded over the past decade or so, has made important strides in characterizing the diverse users of climate information (be they local fisherman and farmers or national political leaders); the mechanisms for distributing climate information; the impacts of climate information on users and their institutions. This literature provides the necessary foundations for constructing a general classification of user types, capabilities, attributes, and information sources. This classification can then be tested and refined,

1. This is not the place to flesh out this argument, but see, e.g., Schelling (2002), Pielke and Sarewitz (2003), Rayner (2004), and Victor et al. (2005). While some would regard the coming-intoforce of the Kyoto Protocol as evidence of progress in this realm, no responsible scientific voices are claiming that Kyoto will have any discernible effect on negative climate impacts.

using standard techniques such as case studies, facilitated workshops, surveys and focus groups. Given the breadth of potentially relevant stakeholders, such a demand side assessment would need to proceed by focusing on particular challenges or sectors, such as carbon cycle management, agriculture, ecosystems management, and hazard mitigation.

5.2. Supply side assessment

Perhaps surprisingly, the detailed characteristics of the supply side – the climate science community – are less well understood than those of the demand side. One reason for this of course is that over the past decade or so there has been some programmatic support for research on the users and uses of climate science, but no similar research on climate research itself. Potentially relevant climate science is conducted in diverse settings, including academic departments, autonomous research centers, government laboratories, and private sector laboratories, each of which is characterized by particular cultures, incentives, constraints, opportunities, and funding sources. Understanding the supply function demands a comprehensive picture of these types of institutions in terms that are analogous to knowledge of the demand side, looking at organizational, political, and cultural, as well as technical, capabilities. Such a picture should emerge from analysis of documents describing research activities of relevant organizations, from bibliometric and content analysis of research articles produced by these organizations, and from workshops, focus groups, and interviews. The result would be a taxonomy of suppliers, supply products, and research trajectories. As with the demand side assessment, the scale of the research enterprise suggests that this assessment process should build up a comprehensive picture by focusing sequentially on specific areas of research (such as carbon cycle science). This incremental approach also allows the assessment method to evolve and improve over time.

5.3. Comparative overlay

Assessments of supply and demand sides of climate information can then form the basis of a straightforward evaluation of how climate science research opportunities and patterns of information production match up with demand side information needs, capabilities, and patterns of information use. In essence, the goal is to develop a classification, or "map," of the supply side and overlay it on a comparably scaled "map" of the demand side. A key issue in the analysis has to do with expectations and capabilities. Do climate decision makers have reasonable expectations of what the science can deliver, and can they use available or potentially available information? Are scientists generating information that is appropriate to the institutional and policy contexts in which decision makers are acting? Useful classifications of supply and demand functions will pay particular attention to such questions. The results of this exercise should be tested and refined via stakeholder workshops and focus groups.

The 2 X 2 matrix shown in Fig. 1 schematically illustrates the process. We call this the "missed opportunity" matrix because the upper left and lower right quadrants indicate where opportunities to connect science and decision-making have been missed. Areas of positive reinforcement (lower left) indicate effective resource allocation where empowered users are benefiting from relevant science. As discussed above, this situation is most likely to emerge when information users and producers are connected by, and interact through, a variety of feedback mechanisms. Areas of negative interference may indicate both opportunities and inefficiencies. For example, if an assessment of demand reveals that certain classes of users could benefit from a type of information that is currently not available (upper left), then this is an opportunity—if provision of the information is scientifically, technologically, and institutionally feasible. Another possibility (lower right) would be that decision makers are not making use of existing

		Demand: Can User Benefit from Research?	
		YES	NO
Supply: Is Relevant Information Produced?	NO	Research agendas may be inappropriate.	Research agendas and user needs poorly matched; users may be disenfranchised.
	YES	Empowered users taking advantage of well-deployed research capabilities.	Unsophisticated or marginalized users, institutional constraints, or other obstacles prevent information use.

Fig. 1 – The missed opportunity matrix for reconciling supply and demand.

information that could lead to improved decisions, as Callahan et al. (1999) documented for some regional hydrological forecasts. An important subset of the problem represented in this quadrant occurs when the interests of some groups, for political or socioeconomic reasons, are actually undermined because of the ability of other groups to make use of research results, as Lemos et al. (2002) demonstrated in a study of regional climate forecasts in northeast Brazil. Finally (upper right), research might not be relevant to the capabilities and needs of prospective users, as Rayner et al. (2002) demonstrated in their study of water managers.

5.4. Institutional context

Decisions emerge within institutional contexts; such contexts, in turn, help to determine what types of information may be useful for decision-making. Supply and demand must ultimately be reconciled within science policy institutions, such as relevant government agencies, legislative committees, executive offices, non-governmental advisory groups, etc. Institutional attributes such as bureaucratic structure, budgeting, reporting requirements, and avenues of public input, combine with less tangible factors including the ideas and norms embedded within an institution, to drive decision-making about the conduct of research and the utility of results (e.g., Keohane et al., 1993; Kingdon, 1984; Laird, 2001; Scho¨n and Rein, 1994; Wildavsky, 1987). How do research managers justify their decisions? Are those justifications consistent with the decisions that they actually make? What ideas or values are implicit in the analyses and patterns of decisions that the institution exhibits? What incentives determine how information is valued? These sorts of questions can be addressed through analysis of internal and public documents, interviews, and public statements about why and how research portfolios are developed. McNie (this issue) provides a more thorough discussion of what is known about how science policy institutions help mediate supply and demand. This remains a key area for additional research, but is largely beyond the scope of our discussion here.

Our analysis of the evolution of the climate science enterprise in the U.S. indicates that policy assumptions and political dynamics have largely kept the supply function insulated from the demand function except in the area of the international climate governance regime (e.g., Pielke, 2000a,b; Pielke and Sarewitz, 2003). Some modest experiments, notably the RISA (regional integrated sciences and assessment) program of the National Oceanographic and Atmospheric Administration, have sought to connect scientists and research agendas to particular user needs at the local level, but these lie outside the mainstream of the climate science enterprise.[2]

A research effort of the type sketched here can illuminate how well climate science supply and demand are aligned and who benefits from existing alignments. It can highlight current successes and failures in climate science policy, identify future opportunities for investment, and reveal institutional avenues for, and obstacles to, moving forward. Consistent with our perspective throughout this paper, the value of the method will in great part depend on how receptive science policy makers are to learning from the results of such research. We fully accept, of course, that knowledge generated about science policy is subject to the same pitfalls of irrelevance, insulation, neglect, mismatch, and misapplication that motivate our investigation in the first place. But our understanding of the current context for science policy decision-making gives us two reasons for optimism. First, the fundamental justification for the public investment in climate science is its value for decision-making. This justification, repeated countless times in countless documents and public statements, thus defines a baseline for assessing accountability and measuring performance via the type of approach we have described here. Second, and of equal importance, the very process of implementing the method we describe will begin to create communication, reflection, and learning among science policy decision makers and various users and potential users of scientific information hitherto unconnected to the science policy arena. In other words, the research method itself creates feedbacks between supply and demand that will expand the constituencies and networks engaged in science policy discourse, expand the decision options available to science policy makers, and thus

2. More information on how the RISAs seek to reconcile supply and demand of climate information can be found at: http://www.sciencepolicy.colorado.edu/sparc/research/projects/risa/risaworkshop05.html expand the opportunities to make climate science more well ordered. Undoubtedly, institutional innovation would need to be a part of this process as well, given the scale and scope of the climate science enterprise and the potential user community.

As a first step toward testing both this method (which should, of course, have broad applicability beyond climate change science) and the specific hypothesis that climate change science is far from well ordered, we convened two workshops to consider supply of and demand for science related to the global carbon cycle. Carbon cycle science is a high priority area of focus in climate change science, with annual public expenditures in the U.S. in excess of $200 million. Research priorities have been established largely in the manner described above, with little engagement between supply and demand sides (Dilling, this issue). Nevertheless, the investment in carbon cycle science is justified in terms of its value for a variety of information users in industry, agriculture, government, and other sectors (Dilling et al., 2003).

Our workshops[3] brought together leading carbon cycle researchers, science policy decision makers, and users representing "carbon cycle management" decision contexts such as urban environmental planning, energy production, agriculture, and emissions trading. Perhaps not surprisingly, most users reported that they benefited little, if at all, from recent advances in carbon cycle science (the single exception being the user engaged in developing emissions trading schemes), and, importantly, that they would greatly welcome specific types of knowledge and information that could enhance their capacity to make effective "carbon management" decisions. The extent to which this poor reconciliation between supply and demand reflected the inability of users to take advantage of relevant available information (lower right quadrant in the matrix above), versus a failure to generate relevant and usable scientific information (upper left and right quadrants), awaits further analysis and a more rigorous implementation of our method (guided by what we learned during the workshop). But the larger point is that this level of reconnaissance supports the hypothesis that the science is not well ordered, as well as the prospect that a better reconciliation of supply and demand is both possible and desirable.

6. Conclusion: enhancing public value in public science

In the public sector, science policy decision-making is mostly about how to allocate marginal increases in funding among existing research programs. At the same time, such allocation decisions are usually justified in terms of their value in pursuing societal outcomes extrinsic to science itself. In a world of limited science resources, then, it would seem more than sensible to bolster such justifications with better understanding of the implications of science policy decisions for societal outcomes. Nevertheless, consideration of how alternative research portfolios might better achieve stipulated societal outcomes is not a regular part of science policy discourse or decision processes.

There are several reasons for this, including:

1. The widespread belief that more science automatically translates into more social benefit;
2. The insulation of science policy decision processes from the contexts within which scientific knowledge is used;
3. The capture of science policy decision process by narrow political constituencies (drawn from either the supply or demand side);
4. The natural resistance of bureaucratic decision processes to changes inside the margins;
5. The absence of analytical frameworks and tools that can reveal connections among science policy decisions, the supply function for science, the demand function for science, and the effective pursuit of stipulated societal outcomes.

Much of our work (as well as that of a number of colleagues) in recent years has begun to consider how to develop such analytical frameworks and tools (e.g., Bozeman, 2003; Bozeman and Sarewitz, 2005; Garfinkel et al., 2006; Guston and Sarewitz, 2002; Pielke et al., 2000; Sarewitz et al., 2000). This

3. For more information, see: http://www.sciencepolicy.colorado.edu/sparc/research/projects/rsd/ccworkshop05.html work is stimulated by the possibility that scientific priorities and societal needs are poorly aligned in a number of critical areas. The challenge for scholarship, in our view, is (a) to identify particular cases where the promises upon which scientific funding are predicated are not being effectively met, and, more importantly, (b) to show that plausible alternative research portfolios might more effectively meet these promises. The challenge for science policy is to draw on such findings to enable better decisions about the allocation of limited resources.

In this paper we have outlined one way to conceptualize a desirable connection between science policy decisions, science, and social outcomes: via a reconciliation of the supply of and demand for science. We have offered a straightforward method for developing knowledge that could facilitate such a reconciliation, and an example – climate change research – illustrating the method's application. In doing so, our larger purpose is to challenge science policy researchers and science policy decision makers to seek ways to formalize and to make analytically tractable the neglected, researchable question that must lie at the heart of a meaningful science policy endeavor: how do we know if we are doing the right science?

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NAVIGATING THE UPSTREAM BOUNDARY: THOUGHTS FOR IMPROVING SCIENCE POLICY DECISION-MAKING

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Workshop question: "How can scholars who study science and innovation policy contribute more effectively to the needs of policymakers facing decisions about science and innovation policy?"

The fundamental problem of science policy, according to Sarewitz and Pielke (who draw on the work of many others), is the disconnect between the supply of and demand for scientific knowledge and information. (Sarewitz & Pielke Jr., 2007) Policymakers who make decisions about science funding -- that is, the type and amount of science to be funded across a range of disciplines and areas -- fail to make strategic decisions that meet the needs of the wide range of decision-makers who need scientific knowledge and information as inputs into *their* decisions. As a consequence, the supply of scientific knowledge and information that flow from science policy funding decisions frequently fail to meet the needs of decision-makers. In their analysis, Sarewitz and Pielke identify through the use of a matrix three situations in which scientific "supply" fails to reconcile with scientific "demand": 1) users can benefit, but relevant information is not produced (research agendas may be inappropriate); 2) users can neither benefit from research nor is relevant information produced (research agendas and user needs are poorly matched and users may be disenfranchised); and 3) relevant information is produced but users cannot benefit from the research (unsophisticated or marginalized users, institutional constraints, or other obstacles prevent information use).

The failure of science policy makers to make strategic decisions about research portfolios stems from the dominant science policy paradigm that scientific research benefits all equally, that science research priorities are best determined by the scientists themselves, and that society as a whole benefits from scientific research in direct proportion with its level of funding. The assumption that the societal benefits of investments in scientific research can be projected simply by the amount of money spent has been amply skewered by Sarewitz, Pielke, and many others. But as long as that paradigm is dominant, science policy makers are off the hook for the politically difficult task of making decisions involving trade-offs between desired societal outcomes and alternative investment portfolios. The sole decision they face is the total amount of funding, which, despite the changes of political winds and economic fortunes, has remained remarkably stable for the last 25 years in the U.S. (Sarewitz, 2005)

As a result, science policy decision makers do not need to explicitly consider the societal outcomes intended to be achieved by scientific research. Or, as Sarewitz and Pielke put it, the only question science policymakers ask is "how much?", not "what for?" However, even if policymakers wanted to achieve an explicitly considered societal outcome, we still lack a model that would assist policymakers in deciding whether one alternative portfolio would be more likely than another to achieve it.

Changing the science policy decision making process

In part, Sarewitz and Pielke respond to this concern by suggesting that changing the *process* of making science policy decisions could improve the likelihood that such decisions would be more beneficial to society as a whole. This suggestion is driven by concept of "well ordered science", an idealized vision of science where all of the society's needs for scientific knowledge and information are met seamlessly and equally through the science policy decisionmaking process, thereby optimizing the benefit of science for society as a whole.

The first part of changing the process of science funding decisions is to change the nature of the question being asked by decision-makers from "how much" to "what for" and "why"? Sarewitz (Sarewitz D. , 2005) has identified ten questions that would begin to change the nature of the science policy decision-making process:

1. What are the values that motivate a particular science policy?
2. Who holds those values?
3. What are the actual goals that the policy is trying to achieve?
4. What are the social and institutional settings in which the R&D information or products will be used?
5. What are the reasons to expect that those are settings for effectively translating the results of R&D into the goals to justify the policy?
6. Who is most likely to benefit from the translation of the research results into social outcomes?
7. Who is unlikely to benefit?
8. What alternative approaches (true either other lines of research or nonresearch activities) are available for pursuing such goals?
9. Who might be more likely to benefit from choosing alternative approaches?
10. Who might be less likely to benefit?

Pielke (Pielke Jr., 2007) also emphasizes the importance of involving *all* stakeholders in the negotiation and bargaining process (i.e. politics) that is currently captured by privileged interests (universities, scientific societies, federal agencies, and certain advocacy groups) who stand to benefit most directly from increasing the science budget. Opening up the process to a much broader array of stakeholders with an interest in the outcomes of research is an important part of democratizing the process to ensure that society as a whole receives the maximum benefits from scientific investments. It is also an essential component of answering the "what for?" and "why?" questions posed above.

Expanded participation is also part of the solution toward a more explicit linkage between science policy funding decisions and scientific knowledge and information needs of a broad range of "downstream" decision-makers. Sarewitz and Pielke described their work in identifying a broad range of potential users of climate information as a means of illustrating this problem.

But expanded participation alone is not likely to be a solution for reconciling decision maker needs with scientific research choices – or in other words to reconcile supply and demand. Self-identification of research needs is one part of the process, to be sure, but by itself will still far short of meeting the goal of optimizing research for societal benefit. One well-recognized problem is that potential users of scientific knowledge and information may not be aware that such information could be useful or that it could be produced. Potential users "do not know what they do not know" and therefore cannot articulate a demand for potentially useful scientific information. (Guston, Jones, & Branscomb, 1997) As other research has shown, information and knowledge alone is not sufficient to ensure its use by downstream decision-makers. Information needs to be accessible, relevant, salient, and credible for use by decision-makers. For that reason, boundary organizations have been created to help make evaluate and synthesize scientific and technical information to make it more useful to downstream policy-makers. (Guston, 2001) And finally, as Pielke has written, not all "demands" for scientific information will actually lead to better decision-making since many decisions are actually over conflicts about values or are otherwise unlikely to be resolved by "more" scientific information -- despite the perception to the contrary. (Pielke Jr., 2007)

Outside of an improved process for science policy decision-making intended to open up the process to all stakeholders, it is not clear whether we can do a better job of choosing among alternative science portfolios on the basis of being able to predict whether one is more likely than another to achieve the desired societal outcome. While work is being done (see, e.g., Bozeman), we don't yet seem to have a clear theory or model to be able to predict which science portfolios would be better than another to meet a particular societal outcome. As Sarewitz and Pielke acknowledge, for example, we don't really know whether the best route for advancing human health would be to research molecular genetic origins of disease versus environmental, behavioral, or other origins. Additional research on ex post evaluations of research decisions may be helpful in creating a better understanding of the linkages between science policy decisions and downstream policy-making using scientific information. (Herrick & Sarewitz, 2000)

Improving Upstream Science Policy Decisions

As analyzed above, the disconnect between the supply of and demand for science stems less from the demand side than from the supply side; the failure to reconcile the two sides comes largely (though not exclusively) from the insulation of the supply side decisions from the demand side needs. Solving this problem, then, requires a change in the science policy decision-making process.

Changing the science policy decision-making process is a daunting prospect. Change can only take place to the extent that the decision-makers themselves choose to change the process. Given the strong political forces that align to maintain the current dysfunctional system, along with the dominance of the "linear science" paradigm, it is difficult to see how the system will be changed. Sarewitz acknowledges that the US system for science policy is so decentralized and so captured by privileged interests that it is virtually impossible for it to engage in strategic priority setting. (Sarewitz D. , 2005)

Yet there may be a way to institute some of the procedural changes that have been suggested as a means of improving the science policy decision-making process, in at least part of the US budget process. Just as boundary organizations have been created to help translate scientific knowledge into information that can be used by downstream policymakers, a similar type of "upstream" boundary organization could be created to help science policy decision makers reconcile supply and demand. The boundary organization could reach out to the broader stakeholder community that is often underrepresented in budget policy discussions, identifying potential research needs connected to broader societal outcomes. The boundary organization could help navigate the three areas of missed opportunities, helping to ensure that relevant information is produced and that users can benefit from the research. Perhaps most significantly, the boundary organization could raise explicit value choices about outcomes and objectives and present an array of alternative science policy funding proposals in the mode of a "honest broker", not as an advocate. In addition, the boundary organization could help assess ex post evaluations to help policymakers better understand linkages between science policy decisions and societal outcomes. Such an organization, of course, could not possibly hope to track the thousands of funding decisions made by federal granting agencies but could at least provide some broader brush perspectives that are currently entirely lacking.

While such a boundary organization could be set up to work with Congress, similar to a Congressional Budget Office or Office of Technology Assessment, it is unlikely to work well in the decentralized, time compressed, and highly politicized congressional budget process. A more promising approach would be to focus on the budget process as it is assembled in the executive branch by the Office of Management and Budget and, to a much lesser degree, the Office of Science and Technology Policy. To be sure, the budget process also remains decentralized within the executive branch, but the OMB review and approval process is the one point where there's an opportunity to review and approve the science budget as a whole. In addition, the Office of Management and Budget has a long history of instituting procedures to ensure efficient management of government. For example, OMB has been directly involved with the implementation of the Government Performance Review Act, which was intended to establish measurable performance goals for every government agency. OMB has also established procedures for evaluating the cost effectiveness of proposed regulations and even set standards for appropriate scientific evidence to support rulemaking. Making the R&D budget process more transparent, accountable, and measurable in terms of desired impacts should be goals of interest to OMB.

Such an "upstream" boundary organization could be established outside of OMB and OSTP, either as an advisory body (like the President's Council of Advisors on Science and Technology) or as a federally-funded research institute. For example, in the early 1990's, Congress directed NSF to fund a Science and Technology Policy Institute to provide an operational scientific and technical assessment capability to OSTP. For a number of years, STPI was operated under contract by RAND. An independent federally-funded research institute like STPI established for the purpose of helping to reconciling science supply and demand would also have the advantage of linking into the academic scholarship on science and technology policy studies.

Alternatively, OMB and OSTP could also attempt to change the science policy decisionmaking process by grafting procedural changes to agency budget formulations and requests. Agencies could be directed to explicitly consider the "why" and "what for" questions and to make the case for linking specific research proposals to explicit policy outcomes. Agencies could be directed to identify potential downstream users and their information needs. However, given the agencies' buy-in to the linear science model, their own institutional interests in growth and power, and the desire to respond to their own politically powerful constituencies, these procedural changes would be unlikely to make significant changes in agency's behavior.

In any event, the challenge raised by the workshop is to identify how increasing knowledge about the science policy process can be applied in the real world. Just as science policy decisionmakers need to look to downstream users of science and technology information, scholars of science and innovation policy need to understand how the knowledge and information they generate can be made useful to the science policy decisionmakers – or else we face yet another "market failure" to reconcile supply and demand.

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"U.S. INSTITUTIONAL CONTEXT: DIVERSITY OF DEMAND SIDE MECHANISMS"

Comments from Tind Shepper Ryen
Prepared for "Reconciling the Supply of and Demand for Research in the Science of Science and Innovation Policy"
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"Decisions emerge within institutional contexts; such contexts, in turn, help to determine what types of information may be useful for decision-making." [1]

The U.S. will spend $151 billion USD on R&D in the current fiscal year, spread across 13 major agencies or departments.[2] While much effort is spent in the U.S. debating the distribution of this funding by fields of study, decision-makers give comparatively less attention to the methods to better link research to societal outcomes within fields and the unique institutional factors that currently affect research portfolio selection. The publicly funded R&D enterprise in the United States is comprised of a remarkable set of highly disparate government bureaucracies. All of these organizations pursue different policy goals and take varied paths to translate scientific results into decisions. Each has different mechanisms for reviewing, selecting, and funding, research proposals. And government employees most directly involved with R&D are vested with varying amounts of decision-making authority. Grappling with these institutional contexts could greatly improve the efficacy of U.S. attempts to encourage tighter links between science and society. To illustrate, I'll provide a brief, and incomplete, example of these institutional differences using two of the 13 agencies: the National Institutes of Health (NIH) and Department of Homeland Security (DHS).

The NIH has an annual budget of approximately $29 billion USD and is comprised of 27 Institutes and Centers that each focus on research on a particular disease, condition, or biological system. The agency is managed in a top-down approach with the majority of policy and funding decisions made by the NIH Director, some authority vested in the Institute directors, and very little leeway granted to lower employees. The agency primarily funds external research at universities and colleges throughout the country through grants to individual researchers. These researchers respond to funding opportunities announced by the Institutes and written by program managers to reflect the strategic priorities passed down from the NIH and Institute directors. Program managers are subject matter experts in the technical area in which they work, who serve as the Agency's internal experts and as a gateway between outside researchers and agency management. Funding opportunities are geared toward expanding the body of knowledge on a particular topic and not towards development of a specific product. After setting the guidelines for applications, program managers have no authority in the review and acceptance of grant applications, but remain the point of contact for grant applicants and recipients. Instead, NIH grants are approved through external, peer-review and based on the scientific merit and overall impact of an application as determined by experts within the field.

In contrast to this rigorous structure, DHS R&D is highly decentralized. With a much smaller budget of $1 billion USD, DHS also organizes itself into areas based on topic and sets research priorities based on Congressional requirements and the views of upper management. Generally, DHS management selects goals based on desired capabilities without making a determination on what research or technology would best meet that need. DHS gives authority to program managers, who are again subject-matter experts, to design and oversee a program aimed at developing a particular technological capability. Program managers at DHS are given tremendous flexibility to

1. Sarewitz, D., Pielke Jr., R.A. 2007. The neglected heart of science policy: reconciling supply of and demand for science. Environ. Sci. Policy 10, 5-16.

2. AAAS. Analysis of R&D in the FY 2009 Budget. Available at: http://www.aaas.org/spp/rd/prev09tb.htm pursue whatever approach they deem necessary. Unlike NIH, DHS program managers write, review, and approve grants and contracts as they see fit, with no external review and little internal review.

These agencies represent two extremes of U.S. R&D programs. In NIH's case, power to affect the research portfolio is concentrated in upper management and within the research field via peer-review. Decisions on research portfolios at NIH are largely determined at a political or senior career level, with little to no ability for feedback between researchers and end users. At DHS, program managers exercise near complete control on the research trajectory. Here, opportunities for better communication between researchers and end-users depend on the individual running the project. Other agencies exhibit a mix of these traits. The National Science Foundation, for instance, runs on a model similar to NIH's, but program managers have some ability to select grantees. The National Institute of Standards and Technology performs research in-house, and like DHS, gives individual researchers broad power to shape research agendas and communicate with outside users as they see fit.

Efforts to better align the supply of and demand for scientific information will require sound theoretical basis, and adaptation to the practical exigencies faced by government decision-makers. This includes understanding who currently makes decisions about research portfolios and what ability they have to provide incentives for scientists to perform socially relevant research. Because these decision-makers differ among U.S. research agencies, so too should initiatives to improve science policy.

OBSTACLES TO SUSTAINABLE DEVELOPMENT: HOW CLIMATE CHANGE KNOWLEDGE HAS BEEN DESTABILISED IN NORWAY

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Abstract

Being able to appropriating climate change knowledge will be of crucial importance for sustainable development. This article explores possible consequences of the presumed post normal features of climate science with respect to the stabilisation of climate change knowledge in Norway. The article study efforts and actors that has contributed to stabilizing climate change knowledge as well as possible acts of de-stabilization, concentrating on climate scientists, politicians and public authorities, and the media. The analysis of these three important groups of actors showed that the climate scientists have been trying to stabilise the scientific knowledge by stressing the overwhelming amount of evidence and unison character of the scientific knowledge. However the efforts and instruments created to stabilise climate change science have met powerful destabilising forces in the journalistic coverage of the issue. The media discourse has seemed to untangle some of the co-constructionist efforts by framing climate change knowledge as controversial and insecure. Post normal science implies that there exists a kind of public hearing of evidence. As shown in this article, the newspapers to a large extent constituted the arena for this hearing process. But, instead of being an arena that produced and demonstrated evidence of the dominant scientific position, the newspapers became the arena for public deconstruction. Thus, the article demonstrates that it is difficult to construct a post normal logic and a shared field of knowledge production when those that constitutes the arena for it, namely the media, primarily engage in processes of deconstruction.

Keywords: climate change, science-policy relations, media, post-normal science, co-construction

Introduction

Climate change is one of the most important techno-scientific challenges that the world is facing. None the less, it is not yet clear how different groups of actors are appropriating and handling knowledge about climate change and whether or not they are domesticating the knowledge in such a way that it will contribute to maintaining order and supporting sustainable development. This may be related to the nature of the problem, the characteristics of the climate sciences, policy procedures, media representations or a combination of these factors. In this paper, we shall look more closely at the appropriation of climate science into policy in a Norwegian context.

Climate change can be viewed from a myriad of perspectives – biodiversity, agricultural productivity, land use, demographic patterns, energy production and consumption, public health, material wealth, economic development patterns, etc. – and each of these ways of looking at the problem involves a variety of interests and values. Accordingly, each perspective calls on a body of relevant knowledge to help understand and respond to the problem (Sarewitz, 2004). Thus, a lack of scientific knowledge is not necessarily the impediment to reach a mutual scientific understanding of what climate change 'means' and what human actions should be taken. Rather, the real obstacle is the huge bulk of knowledge whose components can be legitimately assembled and interpreted in different ways to yield competing views of the problem and of how society should respond to it (Sarewitz, 2004). Climate science may be characterised as an example of 'postnormal science' (Bray and Storch, 1999; Elzinga, 1997; Funtowicz and Ravetz, 1990). This concept addresses the situation when a considerable amount of knowledge is generated by normal science in several disciplines and the borders between disciplines and the division of labour between science and society has a tendency to dissolve (Funtowicz and Ravetz, 1990). It shares many features with the concept of Modus 2 (Gibbons et al., 1994). For example, in both post-normal science and Modus 2 scientific experts share the field of knowledge production with non-experts, such as stakeholders, media professionals and even theologians or philosophers (Jasanoff and Wynne, 1998). The characterisation of climate science as postnormal suggests that there are comprehensive problems due to a high degree of uncertainty and the potential for disagreement due to tensions between the scientific and political spheres. Nolin (1995) claims from a study of the surveillance of the ozone layer as postnormal science that scientific results are often seen as unproblematic truths. Nonetheless, decision-makers and the media often disregard scientific results that require attention. Researchers both manipulate and are manipulated, and the game of deciding what should count as truth takes place above the heads of large parts of the general public which will be affected by the end result (Nolin, 1995).

This article examines whether the situation with respect to the climate change issue have had similar characteristics by exploring possible consequences of the presumed postnormal features of climate science with respect to the stabilisation and de-stabilisation of such knowledge within the context of Norwegian climate policy controversies. Norway's situation is unique with respect to energy, given the country's considerable oil, gas and hydropower resources (IEA, 2001). The economic dependence on oil and gas, its cold climate, as well as a long-standing tradition of cheap energy supply from hydropower, creates a situation that could effect the appropriation of knowledge about global warming. What has been the Norwegian response to the increasing international consensus regarding the climate change issue (as promoted by the IPCC)? Has the international view been overlooked, transformed or is it helping to produce political consensus in Norway? Have other processes or actors other than those related to climate science been interfering? The answers to these questions will increase our understanding of how climate science has been incorporated into public policy and whether or not it has been characterised as postnormal. Before looking deeper into these questions it is necessary to outline the traditional way of understanding the relationship between science and policy, as opposed to the perspectives coming from *science and technology studies* that will inform this study.

Perspectives on the relationship between science and policy

The role of science in political environmental decision-making has long been acknowledged. The traditional way of understanding the relationship between science and policy is what has been described as "the linear-technocratic model of policy-making" (Grundmann, 2006; Jasanoff and Martello, 2004) in which science and policy are two separate domains where science provides authoritative and "neutral" solutions in the face of competing interests (e.g Lasswell and Kaplan, 1950; Irwin, 1994; Price, 1965; Habermas, 1970). This view is often accompanied by a linear notion of "information transfer" from science to policy by which reduction of uncertainty will lead to clearer policy guidance (Grundmann, 2006). A common assumption has been that environmental decisions would improve by ensuring more and better input from science-based knowledge. Science should enlighten decision-makers and increase public awareness, and this increased awareness should lead to informed and rational political decisions so that conventional wisdom will be spread (Jasanoff and Martello, 2004).

Empirical observations have undermined the validity of the linear model as it has become clear that more science does not necessarily lead to better and more well-informed decisions. It has not been scientific knowledge as such that has produced collective solutions to environmental problems on the international arena, but rather coalitions of normatively and discursively joint actors. Thus, the "speaking-truth-to-power view of science" has been challenged by a number of scholars (see e.g Jasanoff, 1990, Funtowicz and Ravetz, 1993, 1992; Herrick and Jamieson, 1995). The power of science has appeared as limited in many political controversies. Instead of believing that science, unlike every other form of social activity, is subordinate to its own unique norms (Merton 1973 [1942]), there has been an increased awareness of the fact that socially embedded interests and connections are as critical in the creation of scientific consensus as in any other area of human activity (Jasanoff et al, 1995; Collins, 1992). Through historical and ethnographic investigations of scientific practises, researchers have demonstrated that ordinary negotiation processes and trust building are essential to the production of trustworthy scientific knowledge (Collins, 2001; Shapin, 1994; Latour and Woolgar, 1979; Jasanoff and Martello, 2004). These scientific processes are largely parallel to the processes involved when producing responsible political decisions. Thus, it has become increasingly obvious that neither science nor politics has a monopoly on truth or power, and that material facts, institutions and discourses constitute hybrid mixtures of facts and values (Miller, 2001). This article pursues the emerging idea that natural and social order is co-produced through an intertwined intellectual and social process (Shackley and Deanwood, 2002; McKenzie-Hedger et al, 2000, Jasanoff and Wynne, 1998). Since the assumption that politics may be given legitimacy by calling upon an autonomous, independent science has been proven wrong, it is important to develop an alternative understanding that utilises the insights from co-production studies.

The co-construction of climate science and policy

The idea of co-production is well suited in order to understand the emergence and stabilization of new technoscientific objects and framings, like climate change. Co-production offers a new way of thinking about power, as it points out the often-invisible role that knowledge, expertise, technical practise and material objects have in the formation, maintenance and transformation of authority relations (Jasanoff, 1994). According to Jasanoff (2004), co-production takes place along certain well-documented pathways, four of which are particularly prominent: making identities, making institutions, making discourses and making representations. Each of these instruments of co-production may serve varied functions in maintaining order. They may be either morally or metaphysically sustaining, politically sustaining or symbolically sustaining. However, as we shall see there are also de-stabilising forces that are found along these pathways.

The main focus of the article is, as mentioned above, whether and to what degree climate change knowledge has been stabilised in a Norwegian context. Consequently, in this article we study efforts and actors that contribute to stabilizing climate change knowledge in Norway as well as possible acts of de-stabilization. The main concern is how the different instruments of co-production operate when it comes to climate change. How do they stabilize what we know about climate change and how we know it? In order to answer this question we have concentrated on three different groups of actors and their role in relation to these instruments. These groups are (1) climate scientists, (2) politicians and public management authorities and (3) the media. These three groups of actors are of course not the only relevant groups as to whether climate science will be stabilised in a Norwegian contexts. None the less, they are without doubt extremely significant when it comes to the governance and public awareness in this area.

The analysis includes 25 interviews with directors, researchers and advisors from some of the most prominent research institutions dealing with climate change in Norway: the Norwegian Meteorological Institute, Centre for International Climate and Environmental Research, the Department of Geosciences at the University of Oslo, Statistics Norway, ECON Analysis, Point Carbon (a global provider of independent analysis and forecasting for the emerging carbon emission markets), as well as the Norwegian Pollution Control Authority. The interviews were conducted between April and November 2005. In addition, seven politicians (mostly members of parliament) and three leading bureaucrats in the central public management were interviewed during March – May 2006.

The policy documents used in this paper were found by searching for the expressions climate policy (“klimapolitikk”) and climate change (“klimaendring”) between 1999 and 2004 in the ESOP (Electronic Searchable Public Documents) database. This is a bibliographic database containing a complete overview of publications from the Norwegian Parliament and Government from 1971/72 until today. It provides information about what has happened to a Governmental Report, a White Paper etc., making it possible to follow the political process and to find related public documents since documents belonging to the same case are linked together.

The Norwegian Climate Policy, also called the "Climate Report," (White Paper 54, 2000-2001) and the Supplementary white paper to White Paper 54 (2000-2001) were the most important documents in this period and thus the ones that are given most attention in the analysis.

The sources for analysing the press coverage of climate science consist of 394 newspaper articles on climate change in the period from January 2002 until October 2005, printed in 8 different Norwegian newspapers: *Aftenposten, Adresseavisen, Bergens Tidende, Dagsavisen, Dagbladet, Dagens Næringsliv, Klassekampen* and *Nordlys*. The articles were found through the Atekst database which contains the editorial archives of Norway's largest and most important media enterprises.

Co-producing knowledge and policy in relation to climate change

Jasanoff (2004) claims that identities, institutions, discourses and representations created by science and technology can be *politically* sustaining by helping societies to accommodate new knowledge like climate change. This may be achieved without undermining the legitimacy of existing social arrangements; in fact, these arrangements may often be reaffirmed. The activities may also be *symbolically* sustaining by offering substitute markers for the persistent validity of certain familiar dispensations when uncertainties threaten to overwhelm or disrupt them (Jasanoff, 2004). The question is to what extent the co-production of knowledge and policy about climate achieved stability as reflected in Norwegian measures to manage the climate problem. Do we observe a manifest impact of climate science on Norwegian policy-making?

Climate scientists – missing their audience?

Making institutions is a crucial function in the co-productionist account of world-making. With respect to global warming and climate science, a myriad of research institutions, both political and the scientific organizations operating internationally as well as nationally, have been established to develop and stabilize climate science facts. The Intergovernmental Panel on Climate Change (IPCC) established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP, has been the most important institution on the international level and, to a large extent, has had the defining power regarding climate change. The role of the IPCC has been to assess the scientific, technical and socio-economic information relevant to understand the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation in a comprehensively, objectively, and openly way. The IPCC provides regular assessments of the state of knowledge on climate change based mainly on peer reviewed and published scientific and technical literature. Its Second Assessment Report provided key input to the negotiations which led to the adoption of the Kyoto Protocol to the UNFCCC in 1997. The Third Assessment Report (TAR) of the IPCC documented that the climate of the earth was changing. The report showed changes in temperature, ice thickness, precipitation and sea-level-change, which together drew a picture of a world that was in the process of warming up. Based on 35 different scenarios of the development of the atmosphere's content of green house gasses and particles, the climate models estimated an additional global warming of 1.4 – 5.8 °C from 1990 to 2100 (IPCC TAR, 2001).

Norwegian climate science knowledge has been produced through a wide array of different institutions, which all has contributed to the stabilisation of climate change knowledge through their research and dissemination activities. They all insist on the overall scientific agreement that the earth is experiencing global warming due to CO2 emissions partly caused by human activity. Further, these climate research institutions are part of a quite stable system that has traditionally envisioned a clear division of labour between science and policy, where their role is seen as providing best possible facts and ground material which may serve as a basis for policy. Most research communities had some contact with policy-making authorities. Some were even administratively placed under a Ministry and some seemed to look upon themselves as civil servants providing information about climate change to the authorities, the industry and the general public. Most of these institutions had a formal role as providers of information services and some also provided commercial service through commissioned research. Thus, there was evidence of many existing ties between the producers of scientific knowledge and policy-making bodies. Thus, these research environments constituted institutions where climate change knowledge was produced, but they also served as stable repositories of knowledge and power.

Making representations of climate change knowledge were one of the main activities of Norwegian climate scientists. These representations manifested themselves mainly through publications aimed at different audiences, from international journal articles targeted at professionals to articles published in mass media targeted at lay persons.[1]

Clearly, climate change knowledge was represented in policy related documents like public reports and governmental white papers. These may be regarded as societies' "description devices" (Latour, 1987; Latour and Woolgar, 1979). The "Climate Report" (White Paper 54, 2000-2001) maintained that Norway has had an active national climate policy since the end of the 1980s, as Norway was one of the first nations to introduce a tax on CO2 in 1991. The report stated that in order to fulfil the collective obligations in the Kyoto protocol, there would be a need of a broad set of measures in addition to the CO2 tax. Thus the report suggested the following policy instruments on the national level: to continue the CO2 tax, to enter into agreements about emission reduction with businesses and industry that are not included in the current CO2 tax, to use the Pollution Act to demand that industry employ best available technologies and effectively use energy, to stimulate technological development, and from 2008, to institute a national quota system. A broad national quota system was seen as the main instrument. There were also other measures mentioned in the "Climate Report" that we will not discuss here, as they probably would play a modest role, for example voluntary climate plans in the municipalities and the preparation of a national action plans for the development of infrastructure of water-borne heating. On the international level, the "Climate Report" supported the building of capacity and knowledge and the green development mechanism. Consequently, taxes, regulations, and agreements were unquestionably seen as the central instruments in Norwegian climate policy.

The "Climate Report" proposed a broad national quota system enforced from 2008 to 2012, according to the Kyoto protocol. This quota system was intended to ensure that Norway would fulfil their binding emission limitation during the period. The Kyoto protocol and the Kyoto mechanisms were portrayed as one of the rescuing instruments of the future, even though the agreement was known to be too humble to have any real impact on the concentration of green house gasses in the atmosphere. However, the treaty was seen as the first necessary legal step towards other more binding and ambitious agreements in the future.

The White Paper stated that the government was preparing for a long-term and strengthened prioritizing of climate research in Norway. Yet, no specific propositions for a budgetary strengthening of research were to be addressed in the yearly budgetary procedure. Thus, the White Paper made no concrete plans about how much or in what way the research would be strengthened. In spite of advocating technological development to solve the climate problem, the "Climate Report" named no specific technologies for further research, apart from working on reducing CO2 which was explicitly mentioned as a priority area.

One might have expected that Norwegian climate policy would be shaped by the relatively stable knowledge provided by the IPCC in a way that would have meant more severe measures for curbing climate gas emissions. However, the co-production of climate change knowledge and policy was mediated through other sets of knowledge, in particular economics and political concerns, which stressed problems other than climate change. In fact Norway distanced itself further and further away from the Kyoto emissions target in the period as the actual climate gas emissions increased by 8.5 per cent from 1990 to 2005, while the Kyoto protocol allow Norway to increase its emissions by 1 per cent compared to the 1990 level. A report from the European Energy Agency (2007) stated that Norwegian climate gas emissions from the transport sector increased by 27 per cent from 1990 to 2004 while emissions from the gas and oil industry increased drastically in the same period.

1. Climate science knowledge has also been known to be represented through models and scenarios reproduced as graphs and diagrams, the hockey stick being the most famous and perhaps strongest tool in order to stabilise climate change knowledge.

There was little doubt that climate science had made an impact on Norwegian policy on a symbolic level, but in practise the effect of climate change knowledge has been relatively moderately co-produced with policy. Few policymakers also seemed to have developed an identity as climate politicians. Consequently, it seems reasonable to look for deficiencies in the relationship between climate scientists and policy-makers. Had the climate scientists avoided a dialogue with politics or had they mismanaged the dialogue?

Interviews with politicians and bureaucrats, as well as the analysis of public governmental reports and White Papers demonstrated that climate science as represented in the IPCC reports served as a knowledge basis for most Norwegian politicians and bureaucrats having to deal with climate policy considerations. Thus, the making of institutions like the IPCC helped politicians to accommodate the scientific evidence of climate change in a way that reaffirmed the legitimacy of already existing social agreements (such as the Kyoto protocol). The TAR acted as a strong stabilizing force concerning climate change knowledge in a Norwegian context. First, the report served as a unified "state of the art" of climate science knowledge and was widely referred to by both politicians and research communities as 'rock solid' evidence. Second, Norwegian climate scientists were participating in the production of the IPCC reports, thus acting as stabilising forces more directly.

Despite these numerous efforts and activities to stabilise climate change knowledge, there were still difficulties of reaching some of the audiences. One of the most prominent climate researchers in Norway pointed to the fact that one of the largest opposition parties in Norway (the Norwegian Progress Party) had stated in their political program that they did not believe in anthropogenic climate changes. Thus, a political shift could potentially have a huge de-stabilizing effect on the communication and implementation of climate change knowledge.[2]

The appropriation of the climate science was obviously seen as a challenge and as one of the climate scientists pointed out, there had not been enough emphasis on using the scientific knowledge that were available.[3] There seemed to be a common understanding among climate scientists that on one hand the Norwegian authorities (the Progress Party aside) had taken on the scientific reports and incorporated the knowledge provided by the research communities, on the other hand, they "stuck it under the table."[4] This was also to some degree reflected in the interviews with politicians. As voiced by one of the MPs interviewed: she did not have any doubts about the evidence produced by the climate scientists, however, she admitted to using their representation to a small extent and only to illustrate "the big picture". A different (more specific) kind of knowledge was needed in sector-specific policy making and decision making.

Thus, the dialogue between climate scientists and policy-makers did not appear very successful, despite the achievements with respect to institutionalising climate science and providing identity, discourse and representations to climate scientists.

The media – staging climate science disagreements?

According to Jasanoff (2004), solving problems of order frequently takes the form of making discourses. This often happens by giving accounts of experts, persuading sceptical audiences, linking knowledge to practise or action and providing reassurance to various publics. The media has been particularly important regarding the making of the discourse on climate change as the media has clearly been setting the agenda of how climate research reaches the public. According to Nelkin (1995), newspapers are the most important source of information with respect to the dissemination of new scientific knowledge, like climate change knowledge.

The 394 articles on climate change published in leading Norwegian newspapers from January 2002 to October 1, 2005 suggested that the discourse surrounding climate change to a large extent was dominated by the journalists' urge to dramatise the scientific knowledge about climate change. The media coverage in Norway emphasized both certainty and uncertainty at the same time

2. Interview with climate scientist 3.
3. Interview with climate scientist 1.
4. Interview with climate scientist 2.

and conveyed an image of two types of drama. First, they portrayed climate change as a 'Nature-drama', featuring spectacular natural phenomena. This framing was made through the use of strong metaphors and pictures that staged climate changes in sensational ways, through reports of extreme weather and catastrophic incidents in nature, like inundations, hurricanes and long dry spells. It drew upon the picture of a threatened Earth devastated by catastrophes similar to classic Judgment Day prophecies. This kind of sensational writing has long been recognised as typical for science writing and news about science (Nelkin 1995).

The second was a Science drama, emerging from framing climate change in terms of heated scientific controversy. By highlighting scientific disagreement, journalists produced a drama that blurred the rather comprehensive scientific agreement about the main issues related to global warming. For example, Norwegian journalists were quite eager to present statements that went against the Intergovernmental Panel on Climate Change (IPCC) and the opinions of the established research community by giving voice to marginalised climate change sceptics. This strategy has also been revealed in studies of the US newspapers, which found that there were many examples of articles that framed climate change in terms of debate, controversy or uncertainty and where the journalistic balance led to bias (e.g. Antilla 2005). In the study of the Norwegian newspaper coverage of climate change, journalists that were interviewed about their strategies regarding climate change reporting made it clear that 'balancing' as well as framing articles on climate change in terms of drama and controversy was a deliberate strategy. This kind of strategies were used in order to produce drama and excitement, while giving journalists an image as objective and distanced. Such focus on controversy and polarisation was also thought to make the newspaper article more provocative and to thereby gain the interest of readers.

Arguably, these two dramas represented a contradictory view of global warming. On the one hand, newspapers tried to stage 'a state of fear' where climate science was played up to argue that mankind was on the brink of disaster. On the other hand, the Science drama invited a cooling scepticism – there was disagreement, so maybe the dangers were not that imminent. In many of the articles about climate change, global warming was directly linked to reports on extreme weather.

There was also an almost complete lack of articles that discussed possible solutions to the climate problem and the discourse was to a very limited degree connected to discussions around energy usage and energy technology. Exceptions to this rule were discussions about the Kyoto-agreement and trading of CO2 quotas.

Very few politicians did also engage in the discussions of climate changes in the newspapers and it was also difficult to trace a forceful interplay between the scientific knowledge and climate policy in the news coverage of the papers, as the linkage between scientific knowledge and policy measures were very unclear. Consequently, we observed a mediated co-production where the media's tradition of framing news (and science) as very conflict-laden was making the political translations of scientific knowledge less important. Instead, readers of Norwegian newspapers were invited to watch a series of reruns of public proofs of manmade climate change. The media saw it as their responsibility to try out objections and to create debate as the journalists were convinced that it was important to shed light on all views on the issue and even the most marginal ones. Based on the strong efforts to stabilise anthropogenic climate change as a fact by the research institutions, we would have expected that the media debate on climate change would not be seen as mere communication of science, but rather as an attempt to create a political order. However, there was little evidence of political translations where the point would be to transform knowledge into action found in the newspaper coverage. There was a lack of focus on alternatives of action, measures and policy. In one way, the scientific language voiced by the IPCC and other climate change experts persuasively spoke of climate change in a way that aligned well with the Norwegian policy and research institutions. On the other hand, the media discourse induced destabilisation of climate change knowledge as it consistently sought to give voice to climate sceptics and focused on uncertainty, conflict and polarisation among climate scientists.

Concluding remarks: Post normal science and the role of media

This article focuses on the stabilisation of climate change knowledge in Norway. It has tried to answer the question of how socio-technical objects like climate change achieve cognitive as well as political standing within a particular national context. The analysis of three important groups of actors showed that the climate scientists have been trying to stabilise the scientific knowledge by stressing the overwhelming amount of evidence and unison character of the scientific knowledge. Taken as a whole, the climate research institutions and the official policy bear witness of significant efforts of co-construction, as politicians and researchers have endeavoured to achieve stabilisation through the making of representations and institutions. However the efforts and instruments created to stabilise climate change science have met powerful destabilising forces. The strategies of destabilisation are first and foremost performed by the media, as the media discourse seems to untangle some of the co-constructionist efforts in its quest for drama and conflict. Such destabilising efforts have yet to be widely studied in the name of the co-productionist idiom. In the period that this study was carried out, the media proved successful in destabilising climate change knowledge. It is reasonable to suggest that this might have led to the weak political translations that we saw in this particular policy area. As the media was successful in creating uncertainty about the scientific facts, this might have led to the fact that providing solutions and measures that dealt with the problem was not seen as very pressing. In particularly not, if the destabilisation of the climate change knowledge made by the media also had resulted in creating a climate 'sceptical' public. However, this is not to be answered in this article, but a topic for further research.

What does media's role mean for post normal science, then? Post normal science implies that there exists a kind of public hearing of evidence. As shown in this article, the newspapers to a large extent constitute the arena for this hearing process. But, instead of being an arena that produces and demonstrates evidence of the dominant scientific position, the newspapers became the arena for public deconstruction. The scientific debate and arguments portrayed in the media did not reflect the actual scientific debates that went on within the scientific community. It was not the scientific uncertainties surrounding cloud formations or effects of vegetation changes on the climate that was creating the headlines, but rather a focus on marginalized climate skeptics. In this way, one may say that the media produced synthetic scientific controversies, while demonstrating the primacy of criticism over facts. Conclusively, the article demonstrates that it is difficult to construct a post normal logic and a shared field of knowledge production when those that constitute the arena for it, namely the media, primarily engage in a process of deconstruction – deconstructing the facts by inviting all kind of possible contestants into the debate in order to destabilise the fact claims and create uncertainty. Thus, the post normal features of climate science seem to some extent to have undermined the stabilization of climate change knowledge in Norway, and probably making sustainable development more difficult to achieve.

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TOWARD A NUANCED UNDERSTANDING OF CONGRESSIONAL POLICYMAKER DEMAND FOR RESEARCH

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The U.S. National Science and Technology Council (NSTC) states the following definition at the beginning of its research roadmap:

> The science of science policy (SoSP) is an emerging field of interdisciplinary research, the goal of which is to provide a scientifically rigorous, quantitative basis from which policy makers and researchers can assess the impacts of the Nation's scientific and engineering enterprise, improve their understanding of its dynamics, and assess the likely outcomes. Research in SoSP could be utilized by the Federal Government, and the wider society in general, to make better R&D management decisions.[2]

The journal article provided as the focus of this workshop entitled "The Neglected Heart of Science Policy: Reconciling Supply of and Demand for Science" asks the following questions:

- In pursuing a particular societal goal or set of goals, how do we know if a given research portfolio is more potentially effective than another portfolio?
- How might one approach the problem of rigorously assessing the relationship between a research portfolio (or a set of alternative portfolios) and the societal outcomes that the portfolio is supposed to advance?[3]

Each of these efforts could perhaps be better defined if two terms were considered: "policymaker" and "reconciling supply and demand for science." In the first case, a fundamental question may be who is the "policymaker" that is the focus of the research? Different policymakers may have different demands, needs, and expectations for data and information. For example, are the information needs of a policymaker who serves in the executive office of the President the same as a Member of Congress? Are the needs of a Member of Congress the same as that of the head of an agency? Are the needs of the head of an agency the same as the needs of an individual managing an office within that agency? How might the needs of the judicial branch differ? Or those of state and local government officials? Differentiating policymakers may help reconcile the supply for science and technology (S&T) policy academic scholarship with the demand for it.

In the second case, if questions related to "reconciling supply and demand for science" were applied to "science of science policy," what would the responses be? Are S&T policy analysts able to answer those questions for their own research field? What lessons do the answers provide for the application of such questions for other fields of research? The attached presentation entitled "Toward a Nuanced Understanding of Congressional Policymaker Demand for Research" provides some perspectives on these questions.

1. The views expressed herein are those of the author and are not presented as those of the Congressional Research Service or the Library of Congress.

2. National Science and Technology Council, *The Science of Science Policy: A Federal Research Roadmap*, November 2008 at http://scienceofsciencepolicy.net/uploads/SoSP_Report.pdf.

3. Daniel Sarewitz and Roger A. Pielke Jr., "The Neglected Heart of Science Policy: Reconciling Supply of and Demand for Science," *Environmental Science and Technology*, 2007.

Congressional Research Service
Assisting the Congress with its deliberations and decisions

Toward a Nuanced Understanding of Congressional Policymaker Demand for Research

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The views expressed herein are those of the author and are not presented as those of the Congressional Research Service or the Library of Congress.

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CRS-2

Organizations and Individuals Who Influence S&T Policymaking

CRS-3

Key Factors to Consider in S&T Advice and Policymaking

- S&T Community is not represented by one individual or organization. Opinions are consensus-based with groups of scientists and engineers coming together from different perspectives to debate an issue based on the available empirical evidence.
- If there are major disagreements within large portions of the community, however, consensus is not achieved, and taking policy actions in response to a concern can be challenging.
- Organizations may agree on the scientific and technical knowledge regarding an issue, but disagree on what actions to take in response, as their values on a proposed policy may differ.
- Policymakers may be overwhelmed by the abundance of information and the diversity of views from these organizations.
- Scientific and technical knowledge and guidance can provide policymakers with an opportunity to make their decisions based on the best information available, along with other factors they might take into account, such as cultural, economic, and other values, so that societal and economic benefits are enhanced and losses are mitigated.

CRS-4

S&T Policy Policymakers

- Legislative Branch
- Judicial Branch
- Executive Branch

CRS-5

Some S&T Policy Issues That May be Addressed in 111th Congress

- Appropriations, particularly R&D Funding; Science, Technology, Engineering, and Mathematics (STEM) Education Funding; and America COMPETES Act Programs
- Oversight of American Recovery and Reinvestment Act implementation for R&D programs, particularly job creation
- NASA Reauthorization, particularly timing of future space flights
- Climate Change
- Energy
- Healthcare
- R&D Data Access
- Immigration Reform
- STEM education
- Cybersecurity
- Homeland Security R&D
- Nanotechnology Reauthorization
- Patent Reform

CRS-6

Potential Legislative Use of Analytical Information

Function that information serves	Use to which it is put
Support for pre-existing position *Certifies* that the position is right	Political ammunition *Reinforces* advocates' confidence in their stand *Strengthens* coalition *Persuades* undecided members *Weakens* opponents' case and support
Warning *Signals* that a problem is (or is not) severe	Reordering the agenda *Moves* the problem up (or down) on the policy agenda
Guidance *Indicates* better alternatives	Design of activities *Leads* to legislative provisions, amendments, further queries
Enlightenment *Offers* new constructs, new ways of thinking about issue	Modification in thinking *Reconceptualizes* issues *Raises* level of discussion

Source: Carol H. Weiss, Congressional Committees as Users of Analysis, *Journal of Policy Analysis and Management* 8(3): 411-431, Summer 1989.

CRS-7

Some Possible Uses of Policy Analysis in Congressional Decisionmaking

Use / **Activity**	**Substantive** (Develop Legislative Position)	**Elaborative** (Extend & Revise Existing Positions)	**Strategic** (Support Positions Already Taken)
Formulation (Legislative Remedy)	Use study to define problem	Use study to refine position	Study reinforced beliefs on proposed legislation
Information Gathering (Hearings)	Identify hearing topics	Develop Hearing questions	Cite study during hearings
Modification (Legislation Markup)	None due to research design	Draft hearing background statements & speeches	Cite study during committee debate
Deliberation (Reports, Floor Debate)	None due to research design	Identify technical challenges	Cite study during floor debate

Source: Based on David Whiteman, "The Fate of Policy Analysis in Congressional Decisionmaking: Three Types of Use in Committees," *Western Political Quarterly*, 38(2): 294-311, June 1985.

CRS-8

WHITE PAPERS

Two Premises of Policy Analysis: Traditional vs. Interpretive Views

	Traditional	Decisionmaking
Decisionmaking	Rational choice: decisionmakers set goals and maximize utility by choosing best means; prospective rationality; problems can be solved by systematic thinking	Ambiguous goals, uncertain means; decisions not primarily about projecting consequences but about process and organizational legitimacy; retrospective rationality
Politics	Marketplace of preference satisfaction; struggle over whose interests are best met by policies (costs, benefits); aggregate of individual interest = public interest	Polity: collective social struggle to shape issue interpretations and preferences about the public interest; debate and discourse can lead to learning
Information	Objective, ideally conclusive, useful problem-solving tool; reduces uncertainty about the relation between policies and outcomes	Inherently inconclusive; reflects values; partisan; information frames understandings of problems; cause-effect in social/political world is indeterminate
Public opinion	Inattentive, politically unsophisticated citizens whose interests can best be conveyed to policymakers by experts	Potentially attentive and capable citizens who mobilize around issue "frames," to whom policymakers pay attention
Policy process	Linear, stages, subgovernments; decisionmakers and experts; passive citizens; monopoly jurisdictions; incremental change	Nonlinear; constant battle over agenda; politics of ideas; competition over jurisdiction and issue interpretations; dynamic change
Use of policy analysis	Instrument of problem-solving process; used by client or decisionmaker to help make choices among competing policies	Instrument of democratic process; used by policymakers, interest groups, and citizens to interpret issues, discover public interest, and justify actions; symbol of rational decisionmaking

Source: Nancy Shulock, The Paradox of Policy Analysis: If It Is Not Used, Why Do We Produce So Much of It?, *Journal of Policy Analysis and Management*, 18(2): 226-244, Spring, 1999.

Note: Decisionmaking in column two heading is probably meant to be "interpretive."

CRS-9

Potential Model of Three-Step Congressional Decision Cycle and Information Needs

- **Agenda Setting** -- Whether or not to address a particular issue or problem
  - Understanding of cause and nature of issue or problem.
- **Policy Development** -- Development of a legislative response
  - Effectiveness of various legislative options in achieving desired results, without undesirable side effects.
  - Administrative and budgetary consequences of the alternative responses to the problem.
- **Policy Approval** – Variety of provisions evolved in a process marked by bargaining and compromise among Members with differing views.
  - Electoral implications and legislative feasibility of the available policy choices.

Source: M. Kenneth Bowler, Preparing Members of Congress to Make Binary Decisions on Complex Policy Issues: The 1986 Tax Reform Bill, *Journal of Policy Analysis and Management* 8(1): 35-45, Winter 1989.

CRS-10

WHITE PAPERS

Some Possible Limitations in Data and Information Available for Congressional Decision-making

- Incomplete and inconsistent data.
- Roots of the problem are difficult to identify objectively.
- Effectiveness of new policies, unintended behavioral effects, costs, and other economic and social consequences of policy alternatives are frequently difficult to predict with confidence.
- Information at hand may indicate most effective policy option is potentially too expensive, may not be acceptable to majority of Members, or has the potential of causing other problems.

Source: M. Kenneth Bowler, Preparing Members of Congress to Make Binary Decisions on Complex Policy Issues: The 1986 Tax Reform Bill, Journal of Policy Analysis and Management 8(1): 35-45, Winter 1989.

CRS-11

One View of Policymaker Demand and Academic Researcher Supply Perspectives

Policymaking Demand from Academic Perspective	Academic Research Supply from Policymaker Perspective
Policy Objectives: Loosely defined, multiple, and sometimes contradictory.	**Unsuitable for Policymaker Use:** Takes too long, highly critical, and insufficient policy actions.
Timing: Need for research may become apparent too late for research to be done.	**Insufficient Consensus of Researchers**: For every study supporting one view, another provides opposite conclusions.
Who Makes Decisions: Inability to communicate directly with policymaker.	**Focus on Generalities:** Policymakers need answers to specific questions.
Decision-making Process: Research examining feasibility of future actions, and achievement of policy goals is challenging.	**Desire to Evaluate Programs:** Policymakers are more interested in future than past.

Source: David Glover, "Policy Researchers and Policy Makers: Never the Twain Shall Meet?"

CRS-12

WHITE PAPERS

Analytic Resource Decisions

- What kind of expertise is needed? In which issue areas? For which congressional clients?
- Are events likely to push the issue onto the congressional agenda within the reasonably foreseeable future?
- Are there plausible legislative solutions?
- Can analysis make a significant difference to the outcome?

Source: James M. Verdier, "Policy Analysis for Congress: Lengthening the Time Horizon," *Journal of Policy Analysis and Management* 8(1):46-52, Winter 1989.

CRS-13

Potential Situations Where Analysis May Make a Difference

- When an analysis can reach Members of Congress before the issue becomes highly visible, politicized, and before commitments have been made.
- The issue is complex, with multiple facets and a variety of possible solutions.
- Data are available on the extent of the problem, the cost of potential solutions, and the impact on constituencies.
- The research staff providing the analysis has enough credibility for their analysis to be accepted as reliable.
- Events force a decision encouraging Members to pay attention to the analysis.

Source: James M. Verdier, "Policy Analysis for Congress: Lengthening the Time Horizon," *Journal of Policy Analysis and Management* 8(1):46-52, Winter 1989.

CRS-14

Social Science and Decisionmaking

- "Social scientists tend to start out with the question: how can we increase the use of research in decision-making? They assume that greater use leads to improvement in decisions.
- Decision-makers might phrase it differently: how can we make wiser decisions, and to what extent, in what ways, and under what conditions, can social research help?
- These are not the same question."

Source: Carol H. Weiss, "Improving the Linkage between Research and Public Policy," in Laurence E. Lynn, Jr., Ed., *Knowledge and Policy: The Uncertain Connection* (Washington, DC: National Academy of Sciences, 1978).

CRS-15

Ten Guidelines for Providing Research Useful for Congressional Decision Makers

1. **Learn about the history of the issue.** By researching previous arguments, the analyst can identify key interest groups, areas of disagreement and data gaps, as well as changes in context.
2. **Find out who will be making the decision, and what research might be useful to them**. Research directed toward a federal agency research program manager decisions may not be relevant for congressional decision-making. Target individuals and groups who work with and advise that congressional policymaker, discuss research needs, and present research results in a form appropriate to the audience.
3. **Timing is critical.** Present research when it is most likely to receive attention. Generally, it is best to provide information early before positions harden.
4. **Learn everyone's interests and arguments.**
5. **It's OK to think like an academic researcher but don't write like one.** Emphasize the decision at hand, the underlying problem, and options to solve it. Minimize methodology, jargon and equations.

Source: Modified from James Verdier, "Advising Congressional Decision Makers: Guidelines for Economists," *Journal of Policy Analysis and Management* 3(3):421-438, Spring,1984.

CRS-16

WHITE PAPERS

Ten Guidelines for Providing Research Useful for Congressional Decision Makers

6. Keep it simple. Where it is essential to explain complex features of an issue, illustrate them simply, using graphics and examples whenever possible.

7. Focus on distributional effects. Explain what groups will be affected by the proposed measures.

8. Take implementation and administration into account. Don't propose measures that are technically optimal but too complex or costly for an agency to administer.

9. Provide new and relevant data and information. Emphasize a few crucial and striking numbers that focus on how people, particularly individuals within their state or district, are or are not affected.

10. Read the same sources of information as the policy maker. These sources influence their perceptions.

Source: Modified from James Verdier, "Advising Congressional Decision Makers: Guidelines for Economists," *Journal of Policy Analysis and Management* 3(3):421-438, Spring,1984.

CRS-17

House Committee On Science And Technology: 111th Congress Agenda Overview

- Innovation: Maintaining Our Competitiveness
- Energy: Developing Clean Technologies
- Workforce: Creating Jobs of the Future
- Environment: Protecting Our Natural Resources
- Space: Exploring and Inspiring
- Transportation: Building New Types of Infrastructure
- Security: Protecting People from Natural and Man-Made Threats
- Investigations and Oversight: Uncovering Mismanagement and Restoring Scientific Integrity

Source: House Committee on Science and Technology at http://democrats.science.house.gov/Media/File/ForReleases/111thSTAgenda.pdf.

Note: See detailed material attached to this presentation.

CRS-18

Questions for Workshop Participants

- How do we know we are doing the right science of science policy research?
- Does its supply reconcile with congressional policymaker's demands?
- If not, for whom is science of science policy research being conducted?
- And why are congressional policymaker needs not being considered?
- If we do not know how well supply is reconciling with demand, how can we better determine that demand? And once that demand is determined, can the requested information be supplied?
- Are science and technology policy analysts able to answer those questions for their own research field?
- What lessons do the answers to these questions provide for the application of such questions for other fields of research?

CRS-19

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
111th Congress – Agenda Overview

The 111th Congress begins with our nation facing challenges on many fronts: a foundering economy; a climate in crisis; a growing need for energy we produce at home; and our scientific leadership slipping. The keys to solving these problems lie in science, technology, and the American spirit of innovation. In the 111th Congress, the Committee on Science and Technology plans to work on issues including energy technology development, climate and weather monitoring, math and science education programs, nanotechnology, the space program, aviation research, and technical standards for industries from energy to health care to telecommunications. The Committee also will work with the new Administration to implement other critical science and technology priorities.

Innovation: Maintaining Our Competitiveness

Innovation in new technologies has accounted for 50% of our country's growth in GDP over the last 50 years, and science and technology will be key to reversing the economic downturn and staying ahead of many other nations that continue to gather economic strength. The Committee plans to:

- Work with the new Administration and Congress to fully fund the America COMPETES Act
- Reauthorize the National Nanotechnology Initiative and ensure that the U.S. is a leader in the development of nanotechnology
- Restructure national information technology R&D to address current needs
- Examine the growing challenges presented by Internet congestion and the future of communications technologies over multiple mediums
- Address the need for standards, evaluation techniques, and improved methods for characterization in the area of biologic pharmaceuticals
- Continue work on the development of technical standards for interoperability and security of health information technology (health IT) systems
- Work to develop updated policies for encouraging Federally-supported research at labs and universities to be brought into the marketplace

Energy: Developing Clean Technologies

Our dependence on foreign sources of energy, increasing greenhouse gas emissions, the need for a more balanced energy portfolio, and rising energy costs will be solved by science, technology, and innovation. The Committee plans to:

- Work with the new Administration to implement the Advanced Research Projects Agency for Energy (ARPA-E) – based on the successful DARPA model, ARPA-E is tasked with undertaking high-risk, high-reward energy technology development, especially research that is too cross-cutting or multi-disciplinary to fit into the current system, and partnering with the best talent in the private sector, universities, and the national labs
- Conduct oversight on the implementation of energy technology programs authorized in EISA 2007 (solar, geothermal, hydrokinetic, cellulosic biofuels, carbon capture and sequestration, energy storage, smart grid, and energy efficiency programs) and recommend any necessary changes
- Review programs at the DOE Office of Science, including ways to strengthen the linkages between basic energy research, applied energy research, and technology transfer and ways to make DOE lab management more effective
- Address new energy technology challenges, including nuclear reactors and reprocessing, vehicles including heavy trucks, and pipelines for new fuels and CO2

Workforce: Creating Jobs of the Future

When half of the world's workers earn less than $2 a day, our country needs to compete at a higher level – with better skills and higher productivity. The Committee will continue seeking to ensure not only that our nation will produce the world's leading scientists and engineers but also that all students will have a strong grounding in math and science and are prepared for technical jobs in every sector of the economy. The Committee plans to:

- Evaluate STEM education programs across the Federal government and determine how to better coordinate these efforts to make them more effective
- Assess efforts to promote diversity in the STEM workforce and gender equity at academic institutions
- Directing investments across the economy in technologies and entities – including small manufacturers and high-tech firms - to create "green jobs" that boost economic growth

Source: House Committee on Science and Technology, press release, December 18, 2008 at http://democrats.science.house.gov/Media/File/ForReleases/111thSTAgenda.pdf.

Environment: Protecting Our Natural Resources

New technologies are critical to addressing growing global environmental problems including climate change, water shortages, and waste management in economically viable ways. The Committee plans to:

- Address the need for accurate and reliable technologies to monitor reporting and compliance with greenhouse gas emission limits in any climate change cap-and-trade scheme
- Direct more effective coordination of Federal research on water supply, quality, and conservation and set a roadmap for technologies, such as "produced water" technologies, needed to address water issues arising from the interdependency of water and energy resources
- Direct R&D programs to address the environmental and economic implications of electronic waste (e-waste) from computers, televisions, cell phones, and other consumer goods
- Conduct a wholesale review of weather and ocean research at the National Oceanic and Atmospheric Administration, including work on ocean acidification and harmful algal blooms

Space: Exploring and Inspiring

Our country's space policy must continue to include engagement in the most cutting edge research and inspiration for the next generation of scientists and engineers. To do this, NASA will need the resources to fulfill each of its diverse missions - human space exploration, science and R&D, aeronautics, and education. The Committee plans to:

- Work with the new Administration on a multi-year authorization for NASA that balances its missions and ensures that programs such as Earth observations and climate research, aeronautics R&D to address environmental issues, and support for K-12 classrooms and college students, as well as human spaceflight and research at the International Space Station, all flourish
- Review the capabilities of emerging space-faring nations and explore an expansion of international space collaboration
- Address the challenges facing the commercial space industry and determine ways to encourage emerging entrepreneurial space ventures ("New Space")

Transportation: Building New Types of Infrastructure

Traditionally, improving infrastructure has been primarily about building more – more roads, more runways, more structures. The Science and Technology Committee will look at ways to use technology to make existing and new infrastructure more efficient. The Committee plans to:

- Focus surface transportation R&D on intelligent transportation systems, more advanced materials such as pavements, and other technologies to increase energy efficiency and reduce congestion
- Ensure adequate progress on the NextGen air traffic control program, which will rely on satellite technology rather than radar to make air traffic safer, more efficient, and less congested

Security: Protecting People from Natural and Man-Made Threats

Emerging technologies – as well as better uses of existing technologies – can improve the safety and security of our communities and our nation. The Committee plans to:

- Review and refocus Federal disaster mitigation research programs related to fire, wind and earthquakes
- Ensure that the Department of Homeland Security aligns its research priorities with the most critical threats and homeland security needs and ensures that the technology developed meets reliable testing and evaluation standards as well as the needs of end-users.
- Focus research on technologies such as unmanned aerial vehicles and tunnel detection to improve border security

Investigations and Oversight: Uncovering Mismanagement and Restoring Scientific Integrity

In the last Congress, the Investigations and Oversight Subcommittee produced 485 letters requesting Administration documents, recommending policy changes, and requesting GAO investigations and 5 staff reports detailing significant abuses, including how the CDC failed to protect public health when FEMA distributed toxic trailers to hurricane victims and how the Veterans Administration allowed vital scientific disease samples to be destroyed. In the 111th Congress, the Subcommittee will continue to pursue investigations of mismanagement and threats to public safety, including negligence in the NPOESS satellite program and the lack of attention to environmental justice issues at the EPA. In addition, the Subcommittee will work with the new Administration to end the politicization of science at Federal agencies and restore scientific integrity to policy decision-making processes.

Source: House Committee on Science and Technology, press release, December 18, 2008 at http://democrats.science.house.gov/Media/File/ForReleases/111thSTAgenda.pdf.

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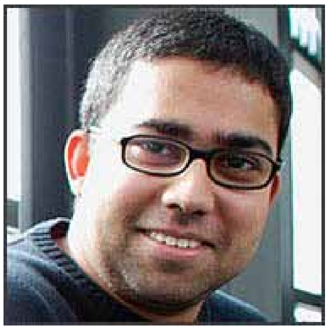

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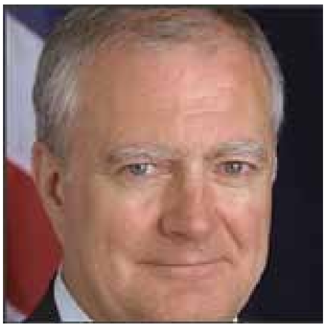

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Roger A. Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in Environmental Sciences (CIRES). At CIRES, Roger served as the Director of the Center for Science and Technology Policy Research from 2001-2007. Roger's research focuses on the intersection of science and technology and decision making. In 2006 Roger received the Eduard Brückner Prize in Munich, Germany for outstanding achievement in interdisciplinary climate research. Before joining the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger is an Associate Fellow of the James Martin Institute for Science and Civilization at Oxford University's Said Business School. He is also a Senior Fellow of the Breakthrough Institute. He is also author, co-author or co-editor of five books. His most recent book is titled: *The Honest Broker: Making Sense of Science in Policy and Politics* published by Cambridge University Press in 2007.

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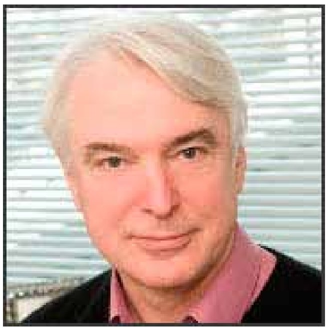

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