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Scholarly science policy models and real policy, RSD for SciSIP in US Mission Agencies

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Abstract Do theories that describe how science and technology policy works accurately characterize programs that aim to contribute to societal benefit? How can the research performed by federal mission agencies contribute to improved decision making? The US Department of Agriculture, the Naval Research Laboratory, and the National Institute of Standards and Technology each have goals of performing research that meets the needs of specific user groups. This analysis examines how institutional factors such as problem definitions, decision-making structures, quality-control mechanisms, distribution of participants, and social accountability guide the production of useful information. This empirical exploration of knowledge production theories fosters an evaluation of existing models of knowledge production, including the linear model, use-inspired basic research, well-ordered science, post-normal science, and Mode 2 science. The ensuing discussion of results concludes that such ideas are either too broad in their prescriptions or not accurately descriptive enough to guide formation of federal research programs that can contribute to usable science and technology products.

Keywords Science policy · Knowledge production · Use-inspired research · Innovation · Federal institutions

The linear model and scholarly alternatives

In the United States, many ideas that have shaped science policy emerged from the writings and influence of Vannevar Bush. Bush's Science-The Endless Frontier (1945) attempted to plan the US science system in the aftermath of World War II. The lynchpin of its proposal was a civilian-led body to support research in the interest of meeting national goals. Bush attempted a system that pursues fundamental theoretical work and successfully connects it to application and societal needs. However, the surviving part of his legacy was an emphasis on undirected basic research (Shapley and Roy 1985) that became codified as

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the linear model of science policy. Bush claimed that improvements in health care, the economy, and national defense rely on increased federal funding for fundamental science, describing industry and government research as an investment in "application of existing scientific knowledge."

Bush maintained that while applied research is within the purview of federal institutions, government also needed to direct funding toward researchers "free to explore natural phenomena without regard to possible economic applications" through the "free play of free intellects" (Bush 1945). The model that emerged partly from Bush's work relies on such fundamental inquiry contributing to a "fund from which the practical applications of knowledge must be drawn." Researchers in applied science and technology development can then draw on this fund as part of a linear process leading from knowledge creation to technology development and societal benefit. While Bush still supported applied research, some of his adherents have taken his work to imply that basic research is the first responsibility of science policy and have pushed an axiology that stresses its primacy (Shapley and Roy 1985; Weinberg 1971).

In addition to policy makers who have objected to a linear framing of science policy (e.g., Brown 1992), science and innovation scholars have criticized the idea of undirected basic research, arguing for steering research toward application (Pielke and Byerly 1998; Gibbons 1999; Sarewitz and Pielke 2007). Some have posited alternative ideas, including use-inspired basic research (Stokes 1997), well-ordered science (Kitcher 2001), post-normal science (Funtowicz and Ravetz 1993), and Mode 2 science (Gibbons et al. 1994). Such ideas represent influential attempts to define or shape modern science policy and to conceptualize the relationship between science and society differently from the linear model. The following paper, using data from case studies on three US agencies: the National Institute of Standards and Technology (NIST), the Naval Research Laboratory (NRL), and the Agricultural Research Service's (ARS) Global Change National Program, provides a description and analysis of how such models apply to institutionalized science, ending with the argument that many propositions either lack the descriptive ability to prescribe policies or the accuracy to be consistent across differing cases and contexts.

Description of science policy models

For the purpose of evaluating how well science policy models describe institutional policies, I have identified the significant characteristics of five models for science policy. These models include Bush's linear model, as understood by the scientific community that has attempted to implement it (Shapley and Roy 1985), Mode 2 science, post-normal science, Pasteur's Quadrant, and well-ordered science. I characterize how the models address different aspects of science policy, including the overall strategy for decision making, claims of who should participate in both decision making and scientific knowledge production, and how they address evaluation and quality control. While the adaptation of Bush's ideas is described above, all the model claims are addressed briefly in Table 1 and more thoroughly in the following text.

Pasteur's Quadrant

Donald Stokes (1997) argued that promoting useful science differs from the argument that all research be applied research by questioning the traditional definition of basic research:

Table 1 Characteristics of different science policy models

Model	Linear model (Bush 1945)	Mode 2 (Gibbons et al. 1994)	Post-normal science (Funtowicz and Ravetz 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 annals of research so often record scientific advances simultaneously driven by the quest for understanding and considerations of use that one is increasingly led to ask how it came to be so widely believed that these goals are inevitably in tension and that the categories of basic and applied science are radically separate" (Stokes 1997, p. 24).

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. Stokes developed a two-by-two matrix, in which the two chief considerations are whether the research pursues fundamental understanding and whether it considers use. When research does both, he utilized the category "use-inspired basic research." Use-inspired basic research consists of "research in an area of basic science ignorance that lies at the heart of a social problem" (Holton 1993). Stokes encouraged use-inspired research over strictly curiosity-driven work to enable more usable science. This approach is evident in the technology policy proposals of President Clinton and Vice President Gore, which endorse basic research with specific goals in mind (Clinton and Gore 1993), and in an NRC assessment of DOD basic research (NRC, 2005), which explicitly cites Stokes in support of use-inspired research.

Well-ordered science

In an essay called, "What kinds of science should be done?" Kitcher (2003) posits "well-ordered science," which works as if there were participation from citizens who are tutored on the scientific possibilities. He argued that the decision-makers should then incorporate the results of this participation into their processes. Kitcher's democratic reconceptualization of science decision making would define scientific value as "that which would emerge from ideal deliberation among ideal agents," (Kitcher 2001) during research prioritization, implementation, and evaluation. Kitcher actually leaves room for outcomes that emulate the result of democratic processes without participation when he writes, "the proper notion of scientific significance to be that which would emerge from ideal deliberation among ideal agents," and which "should satisfy the preferences of the citizens" (Kitcher 2001, p. 117) Kitcher does not define exactly which mechanisms can accomplish this, writing instead that studies of how government agencies set research goals could bring us closer to practical mechanisms that approach this ideal. At least one author (Brown 2004) has criticized Kitcher for his lack of specificity and for not defining well-ordered science more accurately by engaging the expertise of social scientists, many of whom do have experience with evaluating mechanisms for public participation (e.g., Renn et al. 1993; Konisky and Beierle 2001).

Post-normal science

Funtowicz and Ravetz (1993) describe "post-normal science" as an emerging, democratized manifestation of knowledge production that is typical of an arena with high uncertainty, high stakes, or both. According to the authors, post-normal science flourishes in such uncertain situations. These situations encourage that the creation of an "extended peer community" consists of the stakeholders for the issue. Since they include non-technical stakeholders, like the citizens or decision makers affected by the science, the participants in the knowledge production process span the traditional divide between laypeople and scientific experts.

By emphasizing democratic accountability, the authors support operations that can accommodate situations where advice occurs in a value-laden setting with high political consequences. Like Funtowicz and Ravetz (and Kitcher), other authors have argued that increased public participation or democratic accountability could improve the quality of science policy decisions (Foltz 1999; Smith and McDonough 2001; Logar and Pollack 2005; Abels and Bora 2006). Some have proposed public engagement in science as a way to increase acceptance of the results and to allow for information that meets user needs (Wilsdon and Willis 2004).

Mode 2 science

Gibbons et al. (1994) describe a system with two forms of knowledge production, which they refer to as "Mode 1" and "Mode 2." Mode 1 science conforms to disciplinary academic interests, with traditional knowledge production sites (universities, federal laboratories, industry laboratories), and hierarchical decision making. In contrast, Mode 2 science is application-oriented, transdisciplinary, with diffuse, socially accountable decision making. The authors state that both Mode 1 and 2 are necessary for discovery and innovation, but that science that aims at usable information should fall closer to Mode 2 science. Mode 2 is "intended to be useful to someone whether in industry or government, or society in general" (4). With regard to government institutions, the authors wrote, "To what extent such… knowledge producing activities are engaged in Mode-2 knowledge production is open to debate" (Nowotny et al. 2001).

The authors claim to take no position "as to the value of these trends—that is, whether they are good and to be encouraged, or bad and resisted" (Gibbons et al. 1994, p. 1). However, Paul David makes a strong case for the existence of a pro-Mode 2 stance in their work (David 1995). According to its creators, Mode 2 “calls into question the adequacy of familiar knowledge producing institutions,” (Gibbons et al. 1994), including government research institutions. One author later described such socially robust knowledge; “First, it 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’.” (Gibbons 1999, p. C83). They characterize Mode 2 as more valid and legitimate. Such claims seem to argue for increased usefulness, in agreement with research by Cash (Cash 2001), which concludes that social factors, such as salience to users and perceived legitimacy, can increase the usefulness of science.

Terry Shinn (Shinn 2003) brings up the possibility that Mode 2’s influence may be more as an appealing concept than as a description or instigator of actual social change. In a survey of citations, Shinn found both the number of references and the breadth of fields citing The New Production of Knowledge (Gibbons et al. 1994) to be large but did not find much supporting substance. He asked, “Whether the shared vocabulary [of Mode 2] is rooted in structured concepts or is merely a felicitous phrase remains to be seen…. is the ‘New Production of Knowledge’ a metaphor, or just a catch phrase?” (Shinn 2003). Peter Weingart also critiqued Mode 2 science as a description of trends in some small subsets of science, but as one for which the authors “are looking at phenomena on the surface, and, for lack of theoretical point, dramatize them” (592). According to Weingart, despite the claims of Mode 2, “there is no fundamental change in epistemology in sight” (Weingart 1997, p. 592).

From research on NIST, NRL, and ARS, one can make observations about how all of these models apply in real-world setting. Results from case studies on the three institutions can be applied to the same categories seen in Table 1, addressing how the agencies institute prioritization strategies, participation in research and decision making, and evaluation. Such case studies were conducted with data gathered and analyzed using the methods described in the next section.

Methods

Sarewitz and Pielke (2007, pp. 11–14) posited the idea of “reconciling the supply and demand of science,” a modification of economic theory, as a means for conceptualizing relationships between scientific institutions (the supply side) and those groups that use scientific information (demand). When making science policy decisions, the process of reconciliation involves first gaining an awareness of both the supply side possibilities and the demand side opportunities and then reconciling the technical prospects with the users’ context.

The empirical data for each of the institutions studied come from individual studies, on ARS (Logar and Conant 2007), NIST (Logar 2009), and NRL (Logar 2008), evaluating the ability of each organization to match information supply and demand. For a more systematic and rigorous analysis of each of these agencies by themselves, see the individual case studies listed above.

While the role of each institution differs in terms of what kind of science it does and the products it delivers, the important similarity is that they work within the federal science system to attempt mission-oriented knowledge production. I selected cases of federal research institutions that first, had a public record of success at connecting research and application, and second, conducted research that included long-term fundamental work, applied science and technology development. Such information, on how the institutions use their policies to address user needs, also addresses questions of how application-focused research at each place might conform to the claims of science policy models.

I examined the institutions' research prioritization and implementation policies and how they work to benefit users. Along with information gathered from agency documents and other reports on the institution, I conducted semi-structured qualitative interviews (Rubin and Rubin 1995) with staff. The interviews provided information on both formal and informal processes that dictate supply–demand operations, along with attitudes regarding basic research and its relationship to applied research and technology development. Interviewees provided knowledge of funding, evaluation, and prioritization of research programs and worked at levels ranging from research group leaders to divisional superintendents and affiliated personnel.

Important questions in the interview protocol included how research decisions are made, whose input matters in decision making, how decisions incorporate the needs of users, how outcomes are evaluated, and how decision makers and staff conceptualize mission-oriented science. The focus was on the decision processes that govern the institutions, along with how these processes feed into the accomplishment of the mission and user satisfaction.

Science policy at federal mission agencies

While omitting 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.

For NIST, NRL, and ARS to pursue ideal linear model research, the strategies for fundamental research should proceed without consideration of application. As with much federally funded research, these institutions are tied to broad national goals. They also expend significant effort on connecting research to usable outputs.

Table 2 Characteristics of case study agencies

Agency	NIST	NRL	ARS global change
Strategy	Use-inspired basic research with applied science	Use-inspired basic research with applied science on a linear funding model	Use-inspired, but with sometimes conflicting user groups
Participants in decision making	Scientists with input from industry/hierarchical	Scientists with and budget decisions from Navy leadership/hierarchical	Scientists with limited input from farmers/hierarchical
Participants in science	Socially distributed between scientists and a technically literate user community	Scientists with limited military input	Scientists with limited farmer input
Quality control/evaluation	Peer-reviewed publications/impact	Peer-reviewed publications/transition to Navy	Largely publication, with use by farmers or policy makers

Even for fundamental research, NIST laboratories consider application. One way they does so is through a mechanism called the Heilmeier questions, partly designed to aid researchers in assessing the future impacts of their work. The questions encourage research proposals to address both the technical goals and opportunities of a research project, and the project's impact, and include consideration of potential impacts before the project begins. As implemented in many NIST divisions, the Heilmeier questions help to connect NIST research to users' information priorities. Another NIST program, United States Measurement Service (USMS), has gathered information on industry measurement needs through the examination of industry roadmaps and other documentation, along with personal consultation and interviews with industry representatives. Such efforts allow NIST staff to address the question of impact by providing authentic, identified needs that are sourced in the NIST user community.

Structurally, NRL's research budget resembles the linear research pipeline that Bush's ideas suggest, but the laboratory also encourages application-oriented research. Linear funding categories exist as discrete entities on a scale of increasing applicability, which ranges from 6.1, basic research, to 6.2, applied research, 6.3, advanced technology development, and so on (DOD 2004), but NRL processes encourage the representation of Navy concerns at every stage, thus supporting an integration of user needs in decisions. For example, a recent Chief of Naval Research instituted Military Deputies, Naval officers posted at the laboratory. The deputies serve as liaisons between the Navy and NRL, thus facilitating communication between the laboratory and its chief user. Additionally, the military has a "Requirements process," wherein Navy leadership lists its needs. Similarly to the USMS, NRL can utilize such information to work toward an identified need. This both improves the promotional aspect of a new project, since it is easier to obtain funding that meets a voiced need, and enhances the chance that the resultant technology might find use in the fleet. Research leaders at NRL spoke of these processes as necessary bridges between 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.

Finally, ARS also works well to meet application goals, through processes similar to those at the other two institutions. On farm conduct of ARS research projects involve farmers in the research implementation aspect. The research program planning process also includes users of ARS science, in an attempt to include their viewpoints in periodic program evaluation and prioritization activities. Such strategies imply a willingness to supplement expert-driven science prioritization and implementation with input from non-technical peers and thus contradict 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 S&T policy models agrees that for research to be effective, decision makers must address the concerns of their constituents. The three agencies I have 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 by outside interests, and without consideration of use. Mode 2 science calls for research that is transdisciplinary, strongly influenced by non-scientist decision makers and explicitly considerate of use. Much of NRL pursues fundamental research that is disciplinary, weakly influenced by non-technical decision makers and broadly directed toward use. NRL generally succeeds because its research endeavors frequently consider use to the extent that the end product satisfies Navy customers. Some of NRL's customers, such as the Office of

Naval Research, which aims for broad, long-term applicability, are not interested in a specific product but instead judge the research outcome as successful if it plausibly leads to a long-term innovation that can aid the Navy. Funders in the Navy fleet or in other roles can then sponsor additional research projects that transition such fundamental research results into usable technologies. 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.

Similarly, NIST conducts a large amount of fundamental measurement research. In NIST, most notably in the NIST-CU Quantum Physics Divisions, long-term research often goes forward with only an incomplete understanding of the eventual applications or with a broad range of potentialities in play. In programs such as Innovations in Measurement Science, which sponsors longer-term, higher-risk proposals, applicants must still answer the Heilmeier Questions. Although the answer to the fourth Heilmeier Question "What is the impact, if successful?" might be less certain for long-term research, application is still a primary concern for many researchers in the institution. These mechanisms serve to both maintain a context of application and to aid in planning for the transition of technologies from research to industry.

Since ideal linear model basic research includes academic freedom and decision making by experts, little agency science falls under this classification. Although scientists make many of the decisions at these agencies, they are accountable to non-expert decision makers and often work for non-expert information and technology users. Bush did not write that basic science must be removed from practical application; this ideal was included later (Shapley and Roy 1985). His proposal for the creation of a National Research Foundation includes a Division of Medical Research and a Division of National Defense. These suggest a broad field of application for research that decision makers would have to address. If this were the extent of the definition, much of the work within NRL, ARS, and NIST qualify as basic research. However, exponents of the linear model have integrated curiosity-driven research as an ideal to be pursued. This ideal is not conducive to practice in socially relevant institutions (Pielke and Byerly 1998).

Pasteur's quadrant

Pasteur's Quadrant, or use-inspired basic research, adds the idea of application to the concept of fundamental research (Stokes 1994, Stokes 1997). The scientific work within ARS, NRL, and NIST indisputably focuses on use. The former Director of NIST invoked Stokes when he said, "we are the closest thing that our government has to the use-inspired basic science" (Jeffrey 2007), and NRC evaluations of DOD fundamental science categorize it as occurring within Pasteur's Quadrant. With mechanisms like the USMS, military requirements, and other decision tools for assessing how research might contribute to mission fulfillment, the agencies do integrate fundamental research and application.

Pasteur's Quadrant is not explicit about how decision making should occur; Stokes did write that scientists should be the ones to address project-level decisions due to complexity. For aggregate-level policy, the political process can make broader judgments on societal need (Stokes 1994). ARS's global change research program responds to national political dictates on what is useful, by addressing national- or international-level needs for information, such as for the Kyoto Protocol negotiations in the mid-2000s. While part of the program is use-inspired due to larger-scale political processes, agency scientists also work to pursue win–win science that meets both politically derived needs and specific management requirements of the typical agricultural producer.

In NRL and NIST, the political process does not tightly dictate on-the-ground operations in the units I examined. Political processes define the mission and budget for the agencies, but decision makers and researchers have some flexibility in managing their work to meet user needs. In NRL, projects can proceed as long as investigators find a willing sponsor. NIST researchers are responsive to national-level concerns, especially within new initiatives and other larger-scale federal efforts. However, while the proposal process asks for project impact, the researchers can decide on the project they propose, and they are responsible for shaping that process to create impact. For all three institutions, decision making at the larger scale and at the more focused scale (including research implementation) follow Stokes. All three case studies describe agencies that pursue useful knowledge through Pasteur's Quadrant.

Well-ordered science

In the case study institutions, policies do include the interests of a limited public but are never "democratic" in the strict sense of the word. This is mostly due to the need for accountability. The executive branch needs to be accountable to the greater public, rather than just a user community; to do so, agency decision makers need to be responsible for decisions and their outcomes. A limited public still participates. In ARS, NIST, and NRL, the participants are typically comprised of information users. At NIST and ARS, most of the decision making is in the hands of agency personnel, and the "well-ordered" part of the science process manifests in their input sources for making. Strategies that foster participation during intelligence gathering include the military deputies at NRL, periodic planning workshops at ARS, and the USMS at NIST. This inclusion of identified users guarantees the involvement of the limited public, where the constituency is the group that science policy decisions affect the most and who thus have the most at stake. Kitcher also demands that the process includes a public who is tutored in the technical potentials. In NIST, the user community is a technical community, while in ARS and NRL, the users range from technical experts to laypeople with enough interest to become tutored, such as a farmers' groups interested in the prospects for carbon sequestration in soils.

Kitcher never maintains that the mechanisms for well-ordered science have to be democratic in actuality; the result merely has to mimic the decision made by a democracy. Case studies also included well-ordered mechanisms that were not inclusive of the public. At NIST, the addition of user considerations in tools such as the economic impact studies, USMS, and the Heilmeier questions buttress the personal interactions. Some of NIST's laboratory planning tools, which attempt to include impact to users, and an authentication process for such impact, explicitly fold user concerns into decision making. NRL and ARS also have means of integrating user concerns without including users, but these tend to be less formal.

NRL must account for customer needs because Navy personnel make many of NRL funding decisions. Navy admirals are responsible for expressing the aggregate interest of the Navy, so a limited public controls much of the process. If the admirals who have influence over NRL funding decisions do take the needs of the fleet into account, then the result of the science will be, to an extent, well-ordered.

An approximation of well-ordered science also occurs during research evaluation and implementation. For example, industry scientists can work at NIST and help to steer research toward a useful outcome. The Nanofab is a facility that exists for use by industrial firms pursuing nanotechnology research, allowing users to conduct the research as principle investigators at NIST. NIST and ARS both incorporate user viewpoints during implementation and include users during the research process. More visiting researchers than NIST employees work at NIST's campus in Gaithersburg, Maryland. During evaluation, ARS workshops include representatives from the user community. NRL's Navy sponsors also participate in evaluation. Thus, while the democratic participation in institutional science is limited to a smaller public, the agencies all support some approximation of well-ordered science.

However, Kitcher is not specific on what the operationalization of well-ordered science looks like. He does not illustrate what an approximately well-ordered institution might do to become more well-ordered other than perhaps by increasing democratic participation. This impedes the ability to make policy for instilling well-ordered science.

Post-normal science

The concept of post-normal science is, in some way, an extension of the "principle of affected interests." In his book, On Democracy, Robert Dahl (Dahl 1990, p. 64) 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 and Ravetz 1993). As uncertainty and stakes increase, the principle of affected interests mandates that more people might enter the process, since uncertainty can increase the number of people who the outcome might affect, and higher stakes will improve the likelihood of affected interests wanting to play a role in the process.

With regard to society at large, much of the work in the case study agencies qualifies as normal science. While they do perform research with uncertain technical outcomes, these outcomes are not usually high stakes. Meteorology work that can predict and characterize natural disasters is of general interest to many people, but the specific research paths that the Navy uses to improve these forecasts are probably not. Likewise, while the Iraq war is a "high stakes" issue in America, research to better enable military aviators to navigate through and around dust storms is not within the policy concerns of the average citizen. The low amount of controversy surrounding many of these issues makes it normal science. However, within their smaller, more interested communities, the agencies' peer networks extend beyond the confines of normal science, since they include affected interests from the user communities.

Global warming is generally a controversial issue, but most of the interviewees said that the interests of farmers center on (1) their own productivity, and (2) economic concerns (Logar and Conant 2007). Since most do not perceive climate change as a near-term productivity threat, perceptions of the stakes are low. However, some farmers' associations do express interest in one aspect of the research, the possibility of being paid to sequester carbon. These groups participate in this aspect of ARS research. For this relatively high stakes research, reality does conform to the predictions of post-normal science; the peer-network does extend.

While they all work under extended peer networks to a degree, the three case studies do not follow the predictions of post-normal science when compared to each other. For instance, the implications of the case studies for the "systemic uncertainty" characteristic of post-normal science differ. In addition to technical uncertainty, systemic uncertainty includes factors such as the number of legitimate viewpoints that an issue involves, such as the myriad viewpoints that can emerge in land-use decision making. The ARS Global

Change Program may be working under the highest systemic uncertainty. In a highly uncertain climatic future, it is uncertain that they can provide information that addresses real agricultural problems. Additionally, they depend on national-level policy change, such as amendment of the Farm Bill to include payments for carbon sequestration, for much of the work to have relevance. At the same time, the Global Change National Program works with the most limited peer network. Budget cuts have limited the participation of the Agricultural Extension Services, which historically interacted with users, and the mechanisms that ARS has for working with users are limited when compared to those in NRL and NIST. Thus, ARS arguably has the highest systemic uncertainty but least extended peer network.

Mode 2 science

The characteristics of Mode 2 science, as described by Gibbons et al. (1994), include a context of application that takes problems into account, socially accountable decision making, heterarchy instead of hierarchical decision structures, transdisciplinary, socially distributed knowledge production that transcends lay/expert relationships, and norms for quality control that transcend traditional academic peer review.

All three agencies have limited social accountability. ARS does not have formal means for accountability beyond the periodic workshops for program planning. Furthermore, since the Global Change National Program is a response to expressed needs by national-level decision makers, the approval of agricultural producers does not play a large role in the accountability process. The agencies can act as if they are accountable and often do so by making decisions that correspond to the recommendations of their user communities. However, they cannot be fully accountable because the agency decision makers are responsible for institutional decisions.

Additionally, the institutions are firmly hierarchical. As subsidiary to the US Navy, NRL follows the chain of command, especially with regard to funding. Congressional authorization committees have made it subservient to ONR and the Navy fleet. This hierarchy continues downward from the Chief of Naval Research, to the NRL Director of Research, Division Superintendent, and Section Leaders. Similarly, ARS and USDA adhere to the hierarchical order of the bureaucracy. Government agencies do not follow the heterarchical predictions of Mode 2. They also should not be expected to if they are to remain accountable and legitimate to the elected officials that oversee them and, by extension, the public.

NRL, ARS, and NIST also include users during knowledge production, but in limited parts of the process. For NRL and ARS, agency staffs conduct the research, with some participation in research evaluation from users, and occasional collaborative work with other groups. NIST, with its many technically literate users, includes many of them in the scientific work itself.

Mode 2 also entails a “linking together of [knowledge production] sites in a variety of ways – electronically, organizationally, socially, informally” (Gibbons et al. 1994, p. 6). This trend is evident in all three of the agencies. New technologies allow beta testing of computer modeling products and enhanced opportunities for electronic communication with users. These enable user-integrated product evaluation at NRL. Strategies such as on-farm testing of new ARS research, and the institution of the Nanofab as a user-led NIST research facility, are operational arrangements that encourage these linkages. However, while all three agencies use strategies to enhance the socially diffuse nature of their research, they are not transdisciplinary. In transdisciplinary, the technical framework for addressing problems and the skill sets used can shift with changing contexts. As problems change, the disciplinary components of the work should change with it. NIST's Center for Nanoscale Science and Technology (CNST) loosely approaches this; it hires post docs to maintain a flexible work force. CNST can adjust its suite of skills in the relatively short term to address upcoming problems in nanotechnology. This shift may not occur project by project but does encourage flexibility over a shorter term than the career span of the average scientist, which is how Mode 1 operates. The other agencies operate closer to the Mode 1 norm, with much of the work performed by static teams within a specific discipline.

Gibbons et al. (1994) state that Mode 2 research shapes and adapts to context instead of operating from a preexisting operational framework. However, operational rigidity dictates the work within NRL, NIST, and ARS. NRL's Meteorology Division consists of 60–70 scientists in the same field and is thus rigidly disciplinary. Operations, problem focus, and user interactions can change, but much of the division's work will occur in disciplinary and operational isolation. The ARS Global Change staff needs to reconcile its existence within USDA with the outcome gains that could come from altering its research course (Logar and Conant 2007) and thus has limited flexibility. Although it addresses a new problem—global climate change—the program operates identically to the other national programs at the agency and thus does not drastically shape operations to fit context.

The agencies can contribute to more widespread efforts to address larger, multidisciplinary problems. For example, the NRL Marine Meteorology contribution to a single Navy Requirement is usually a component of addressing a larger need. This larger need involves the participation, but not necessarily collaboration, of a number of other research institutions. Instead of organizing around the problem, groups may address their part of the capability gap on their own.

For quality control, peer review is still a significant factor, but other factors play a role as well. Some units within NIST take other measures, such as impact of research and interaction with industry groups, into account. NRL basic science is still largely reliant on publications as a metric, but applied work and technology development focuses on technology transfer as a criterion for quality research. Many in NRL discussed the sponsor as the judge of quality for the work, as did researchers in the ARS. Both groups also spoke of testing products with the potential users of those products. NIST possesses socially accountable assessment structures, such as review by outside experts in NRC panels and industry groups. The use of the USMS as a tool for identifying needs is evidence that NIST is folding these inputs into its decision processes. NRL also does so through the military deputies, the requirements process, and the mechanism of user-funded science.

For the criteria for Mode 2, the institutions represent science efforts oriented toward application, but do so in the absence of heterarchy or transdisciplinary. The agencies vary in their incorporation of new modes of quality control and social diffusivity and largely operate with limited social accountability. However, aspects of agency work, including basic research, do occur in the context of application, when it is defined as a knowledge system that works toward information, "intended to be useful to someone" (Gibbons et al. 1994).

Additionally, 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 scientific curiosity 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. Because of the indistinct nature of Mode 2's definitions (e.g., What counts as full transdisciplinary?), the degree of Mode 2 for an institution is hard to address. However, none of these agencies confirm the vision of Mode 2 science that Gibbons et al. lay out in their books and articles (Nowotny et al. 2003; Nowotny et al. 2001; Gibbons 1999; Gibbons et al. 1994). These government institutions do not possess the socially diffuse decision structures that Mode 2 dictates. This may be where federal science is most like Mode 1 or normal science. In other aspects of the agencies' operations, they incompletely approach some of the Mode 2 ideals or do not do so at all.

My assessment is limited in considering Mode 2 in that I have approached traditional institutions as the appropriate unit of inquiry. Long-serving government agencies may not be likely to represent Mode 2 institutions, which emerge from a more "heterogenous and flexible socially distributed system" (11) than mid-20th century US policy had to offer. However, Mode 2 predicts that many types of institutions, including those that are traditionally Mode 1, will participate in the new form of integrated knowledge production. Scientists from Mode 1 agencies could participate in Mode 2 efforts through collaboration in external groups. However, within these institutions, there were no examples of scientists participating in internal or external activities that were entirely Mode 2. But does the fact that Mode 2 is not fully occurring in these agencies, or within the staff, inhibits the applicability of the research?

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 failure if they can still meet their missions. 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 hinder the implementation of Mode 2. The case studies conform many of the Mode 2 characteristics incompletely, but they also represent progress toward 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). Other characteristics, such as social accountability, are the characteristics they claim to enable this context. Although not all of these attributes are necessary in every case of Mode 2, the authors say that their presence is necessary for coherence and organizational stability.

The authors believe Mode 2 knowledge "calls into question the adequacy" (1) of government knowledge production institutions. However, since an incomplete version of Mode 2 is acceptable in the authors' discussion, and since federal agencies can be successfully application-oriented without fully implementing Mode 2, Mode 2 only questions the adequacy of those Mode 1 institutions that do not consider application. Mode 2 science might be one way of enabling useful information, but the characteristics of Mode 2 science are not universally necessary for the production of such information. NRL, ARS, and NIST are expanding the definition of the research process to include users and operationalizing it in such a way that application becomes an explicit consideration. This has occurred through expansion of whose viewpoints matter in the decision process.

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 had successes in delivering useful science and technology products to their constituencies, and all currently have mechanisms in place to encourage further success. According to the idea of reconciling supply and demand (Sarewitz and Pielke 2007), all three agencies produce some amount of science that matches information supply with user demand.

Success, institutions, and policy models

If one were to define the means of programmatic success as conformance to a particular prescriptive scholarly model, 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 conducted within the social contract. NIST, NRL, and ARS also support a weak reading of well-ordered science, where democratic outcomes need to be emulated but not necessarily fully instituted. They attempt to integrate public concerns into every stage of the process, with some success. Mode 2 dictates that the context of application should shape the conduct of science at every stage in the process, and institutions achieve this, to differing extents. However, in the empirical cases, it is not as consistent or extensive as the Mode 2 authors predict. A large part of this is due to context. These institutions are inhabitants of a larger administration that does not easily support the more fluid, less-rigid kind of science posited by The New Production of Knowledge. However, the agencies are currently working within the flexibility they possess to pursue useful research outcomes. Although Mode 2 might stipulate transdisciplinary, socially nimble institutions, this appears to be unlikely under many government bodies. There may be room for less rigid institutions outside the existing federal structure, but the pertinent question for evaluating Mode 2 is whether institutions can accomplish its application-focused goal within a system that forbids the model's full realization.

All three institutions are able to accomplish the overriding goal of Mode 2 knowledge production, in that they are able, to different extents, to conduct research that delivers results within their field of application. The resulting question must be: Are the other characteristics that the authors posit for Mode 2 necessary for application-sensitive knowledge? Based on these three studies, the answer appears to be that they are not.

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, the important task for mission agencies is to instill considerations of application in different stages of the decision process, within their constraints. Explicit participation of users, along with consideration of the demands of users through non-participatory mechanisms, can enable research leaders to connect their research to a field of application.

Given the importance of context, it is difficult 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 research programs have been uninfluenced by considerations of need while simultaneously successful in contributing to need. Similarly, 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 entirely possible to be successful without following all of the recommendations of Mode 2 authors (see Table 3). In most cases, agencies do not cleanly fall into a yes or no category, but the table does represent the general trend from the available data.

Given that NIST, NRL, and ARS are "familiar knowledge production institutions" (Gibbons et al. 1994) to the point where they have each existed for more than 75 years, one would think that their performance would be compromised and their operations would be closer to Mode 1 science, since Mode 2 is characterized as an emerging phenomenon.

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
Transdisciplinary	No	No	No
Social diffusivity	Yes	Limited	Limited
Quality control beyond peer review	Yes	Yes	Limited

Instead, they all represent some hybrid point on the spectrum between Mode 2 and Mode 1 science.

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 expand participation (Funtowicz and Ravetz 1993). However, the relationship between stakes and involvement does not consistently play out in reality. One issue for post-normal science is the question of "high stakes for whom?" Measurement and standard issues have large consequences for NIST's chief constituents in US industry but do not receive 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 interest of many farmers has meant 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 approaches a level of abstraction that impedes assessment of whether real-world institutions meet his recommendations. Kitcher makes no policy recommendations, instead positing democratic mechanisms as a means for effective science. Because Kitcher is so ambiguous, it complicates assessment of whether a scientific program is well ordered. For example, one could argue that the American electoral system is a successful approximation of ideal deliberation or that an interested monarch can make decisions that "satisfy the preferences of the citizens."

Stokes framed his ideas for "Pasteur's Quadrant" as "completing the linear model" (Stokes 1994), by adding considerations of use. The scientific work within ARS, NRL, and NIST is indisputably use-inspired. Stokes provide a useful conceptualization of theory-driven, application-oriented research, but he 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.

Conclusions

In these cases, the two conditions behind any one institution's conformance to model claims, except those of the linear model, fall into two lines. One is the adoption of policies that allow for the inclusion of problem-oriented, or application-oriented, research. The second is the related condition of adopting user inclusion and input into the decision processes that dictate the research process. While two models, those of Stokes and Kitcher, stop at this point, the others, post-normal science and Mode 2, attempt to more specifically delineate what is needed for effective institutions, and all do so in a manner insufficient to the task.

It might also be that improved models are impossible. Despite being the most well defined and concrete of the discussed models, Mode 2 science is a broad set of criteria that are first, difficult to comprehend and evaluate, and second, overly specific to the point where the goal, a context of application, does not require its conditions, such as trans-disciplinarity. The model does not provide a clear set of recommendations, and the degree to which any institution conforms to its tenets is still highly debatable. If scholarly models became more tightly descriptive or prescriptive, they would likely become more difficult for any one institution to conform to them. On the other hand, as specificity is reduced, the ability to prescribe actionable policies decreases with it.

Furthermore, the problem with science policy models is not one of improving uptake or translation of ideas. While the resemblances between case study agencies and some of the recommendations made in “The New Production of Knowledge” are evident, the key to further advancement in use-inspired research is not full adoption of the ideas from such works, since such adoption is impossible in many circumstances. The key to managing institutions successfully is performing mission-appropriate research with beneficial outcomes for users. Such a task might be aided by the general recommendations of ideas like Stokes’s, but most of the work will have to be done within the context of the institution and outside the broad guidelines of science policy models. Stokes’s ideas are still very valuable ones, but they serve as a guide for taking action, not a dictation of what action should be taken.

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. For example, many of the models posit increased input from users or publics, but the real question for many of these agencies is in how to do so. While the USMS, ARS national program committees, and Military Deputies are all attempts at answering such questions through a muddling through approach, more work on how such strategies alter outcomes for agencies could be helpful, especially in light of other political, regulatory, or financial constraints. In order to make policies for science and technology institutions that allow them to contribute usefully to the innovation process, policy makers require concrete recommendations for successful endeavors. While models such as Mode 2 or well-ordered science can be valuable in instilling the process with loose guidance, empirically grounded advice will be more effective in dictating actual policies at institutions.

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