Wicked Problems and Applied Economics

Sandra S. Batie

The term "wicked problems" is found in many disciplines, including public administration, policy science, health education, ecology, forestry, and business administration, but the term is relatively unknown in applied economics. Applied economics needs to become better acquainted with wicked problems; they are pervasive, and they present challenges if applied economics is to retain its relevance in today's world. This paper explores these challenges but is necessarily exploratory, as widespread recognition of the complexity of wicked problems is leading to new kinds of research, but these research approaches are still evolving. My basic thesis is that normal science assumptions and approaches are inadequate for addressing the complexities of wicked problems in a policy context, but that science, including social science, remains crucial for the development of alternative policies. This exploration, therefore, is about both the characteristics of postnormal science necessary to inform alternative policies designed to address wicked problems as well as their implications for policy contributions from applied economics. Because many wicked problems involve sustainability issues, I will focus mainly on sustainability problems.

Wicked vs. Tame Problems

Examples of wicked problem issue areas include terrorism, global climate change, nuclear energy, healthcare, poverty, crime, ecological health, pandemics, genetically modified food, water resource management, trade liberalization, the use of stem cells, biofuel production, nanotechnology, gun control, air quality, sustainable development, biodiversity, environmental restoration, forest fire management, and animal welfare. Other wicked problems include the locating of not-in-my-backyard (NIMBY) projects (e.g., a freeway or a halfway house); reengineering a food supply chain to address food safety problems; constructing or removing a hydroelectric project; or opening of a new mineral mine.

Wicked problems, which are sometimes called social messes or untamed problems, are dynamically complex, ill-structured, public problems. The causes and effects of the problem are extremely difficult to identify and model; wicked problems tend to be intractable and elusive because they are influenced by many dynamic social and political factors as well as biophysical complexities (Rittel and Webber 1973). Also, most wicked problems are connected to, or are symptoms of, other problems (Carroll et al. 2007). As a result, there is no consensus on what exactly the problem is. Indeed, a wicked problem is not well understood until after formulation of a potential solution, and therefore, the problem definition tends to change over time. However, because of their complex interdependences, wicked problems are never solved (Conklin 2006), but rather they become better or worse (Rittel and Webber 1973).

Wicked problems always occur in a social context, and there can be radically different views and understanding of the problem by different stakeholders, with no unique "correct" view (Horn and Weber 2007). Thus, their wicked nature stems not only from their biophysical complexity but also from multiple stakeholders' perceptions of them and of potential trade-offs associated with problem solving. Identification of solutions becomes as much a social and political process as it is a scientific endeavor (Kreuter et al. 2004). Also, wicked problems are characterized as having high uncertainty associated with them, not only with outcomes but also with the potential causes and effects underlying the problems. In addition, there are multiple stakeholders'

Fellows Address.
Sandra S. Batie is the Elton R. Smith Chair in Food and Agricultural Economics Policy in the Department of Agricultural, Food, and Resource Economics at Michigan State University, East Lansing, MI. Her email is batie@msu.edu.
Thanks are due to Dave Ervin, Patricia Norris, Christopher Peterson, David Schweikhardt, Carol Shennan, Leonard Shabman, and Kurt Stephenson, whose suggestions helped to improve this article.

Fellows Address was presented at the 2008 AAEA annual meeting in Orlando, FL. Invited addresses are not subjected to the journal's standard refereeing process.

Amer. J. Agr. Econ. 90 (Number 5, 2008): 1176–1191

DOI: 10.1111/j.1467-8276.2008.01202.x

Table 1. Summary of Differences Between Tame and Wicked Problems

Characteristic	Tame Problem	Wicked Problem
1. The problem	The clear definition of the problem also unveils the solution *** The outcome is true of false, successful or unsuccessful *** The problem does not change over time	No agreement exists about what the problem is. Each attempt to create a solution changes the problem *** The solution is not true or false—the end is assessed as "better" or "worse" or "good enough" *** The problem changes over time
2. The role of stakeholders	The causes of a problem are determined primarily by experts using scientific data	Many stakeholders are likely to have differing ideas about what the "real" problem is and what its causes are
3. The "stopping rule"	The task is completed when the problem is solved	The end is accompanied by stakeholders, political forces, and resource availability. There is no definitive solution
4. Nature of the problem	Scientific based protocols guide the choice of solution(s) *** The problem is associated with low uncertainty as to system components and outcomes *** There are shared values as to the desirability of the outcomes	Solution(s) to problem is (are) based on "judgments" of multiple stakeholders *** The problem is associated with high uncertainty as to system components and outcomes *** There are not shared values with respect to societal goals

Source: Adapted from Kreuter et al. (2004).

viewpoints with respect to the desirability of alternative outcomes.

Wicked problems can be contrasted with tame problems. While frequently complex and difficult, tame problems are those that can be clearly delineated and solved by experts who produce workable solutions using the analytical approaches of their disciplines (Kreuter et al. 2004). Examples include landing men on the moon; determining the specific source of a food contamination outbreak; identifying the cost effectiveness of different crop practices to reduce soil erosion; or determining the costs and benefits of expanding an irrigation project. Tame problems are characterized by clear definitions of the problems which do not change overtime. Also, the problem definition reveals potential solutions because of clear cause and effect mechanisms. Unlike wicked problems, there is little conflict over the desirability of these potential solutions. Tame problems can be addressed primarily by experts with little or no involvement of stakeholders, and unlike wicked problems, they can be solved.

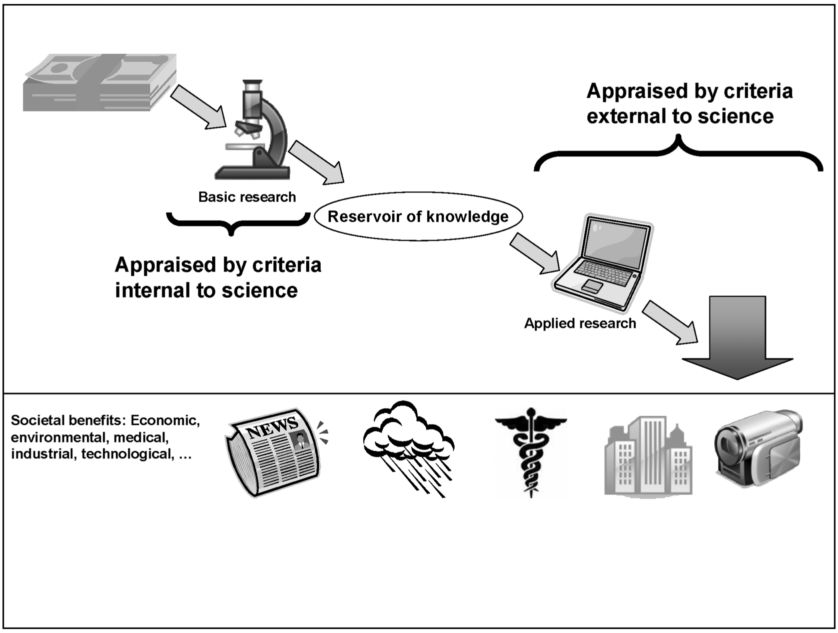
Table 1 summarizes these differences between wicked and tame problems as being about whether there is (1) a common definition of the problem; (2) a direct involvement of stakeholders in problem definition and analysis; (3) a deterministic "stopping rule"; as well as (4) the unique nature of the problem.

Challenges Posed by Wicked Problems

Wicked problems pose a dilemma for normal science activities. Normal science, as defined by Thomas Kuhn (1962) in his book *The Structure of Scientific Revolutions*, is the routine work of disciplinary scientists "puzzle solving" in their paradigm. Normal science research (i.e., conventional or mainstream research) adds to the details of the established theory but does not challenge it or test its assumptions.

Historically, normal science has had a close relationship with the creation of policy alternatives (Funtowicz and Ravetz 1993; Stokes 1997). Since World War II, normal science has been guided by a linear model[1] which is illustrated in figure 1 and can be summarized as: "[B]asic research, conducted by scientists that are largely autonomous, is a

[1] The linear model of normal science and its relationship with policy development can be traced to concepts articulated in Vannevar Bush's 1945 report *Science—The Endless Frontier* (Stokes 1997).



Source: Pielke and Byerly (1998).

Figure 1. The linear model of science

resource for applied research. Applied research is the source of results useful to practical concerns, including policy development" (Pielke 2007, p. 81). In this model scientific findings flow into a reservoir that can then be drawn on by society to create beneficial technologies and outcomes. Basic science is judged by criteria internal to science, such as disciplinary standards, whereas applied research and development is judged by criteria external to science, such as the potential usefulness to society. There is also more status conveyed to those engaged in basic research than to those undertaking applications that involve the integration of science into decision-making processes (Pielke Byerly 1998; Stokes 1997). Many research institutions—universities and agencies—are reflective, supportive, and reinforcing of this linear model of normal science (Bonnen 1986; Peters 2007; Stokes 1997).

With respect to policies and decision making, linear, normal science models maintain underlying assumptions that scientific progress leads to societal progress (Frodeman and Holbrook 2007) and getting the science right is necessary to settle political disputes and for effective policy making to occur (Pielke 2007; Sarewitz 2004). However, as figure 1 illustrates, normal science frequently has a division between those who do the science and those who use it: "Autonomy is implicit in the [linear] model, because the reservoir [of scientific findings] isolates science from society; science assumes no responsibility to apply the knowledge it puts into the reservoir, and society does not set scientific priorities" (Pielke and Byerly 1998, p. 42). This division implies that reducing scientific uncertainty will reduce political uncertainty, and reaching a consensus on the science is a prerequisite for a political consensus and for policy action to occur (Vatn and Bromley 1994).

These assumptions are tantamount to conflating the "what is" and the "what if" products of science with the "what ought to be" product of politics. They are also quite problematic but tend to be more realistic (1) where there is widespread agreement by stakeholders as to what are desirable outcomes as well as (2) where there is low uncertainty surrounding the system components and outcomes of alternative course of actions (Pielke 2007). That is, they tend to be more realistic with the "tamer" problems of society. For example the research to develop a vaccine for a serious human disease falls in this tame problem category. With most vaccines, there tends to be widespread agreement that protecting humans from the disease is desirable, and there is low uncertainty about the system components or outcomes. Thus, for vaccine development the assumptions of the linear model of normal science are apt.

Normal Science and Applied Economics

To illustrate Pielke's points, consider applied economics. As with all disciplines, normal science is applied economists' "bread and butter" work. The *American Journal of Agricultural Economics* showcases normal science research, most of which tends to follow what Lindbloom (1965) calls the "rational analytical method." That is, applied economics research projects normally follow formal decision logic, and the applied economist is the expert—selecting assumptions and methods, defining significance, and using theory (e.g., welfare theory) as criteria to isolate end states such as equilibria or optimal outcomes (Stephenson 2000). Examples include formal benefit-cost analysis, nonmarket valuation techniques, dynamic optimization, multiattribute utility analysis, econometric demand modeling, spatial equilibrium modeling, and willingness to pay estimations. And for much of applied economics policy research, "getting the science right" can equate with "getting the prices right."

Advocates for the rational analytical approach, following the linear model, defend its use in policy making as a systematic and rational way for decision makers to decide between competing ends (Shulock 1999; Stephenson 2000). That is, research can be placed in a reservoir to be drawn out by policy and decision makers as needed. As discussed above, the potential for this research to influence policy is higher when the system components and outcomes are known and probable outcomes are generally viewed as desirable. Thus, the selection of, say, the least-cost alternative to reduce (the relatively tame problem of) erosion is more likely to have policy acceptance than is the identification of the optimal allocation of resources to reduce (the more wicked problem of) perceived global warming threats.

The distinction being made is that within a policy context, there is a difference with "what is" (and "what if") types of research and the "what ought to be" types of research as they address tame and wicked problems. "What is" issues, such as "What are the impacts of land uses given the new Energy Act?" and "what if" issues, such as "What would be the impact on the economy if there was more development of wind power sources of energy?" are appropriate for both tame and wicked problems. Where societal goals are broadly known and accepted, such as in the vaccine research example, researchers can proceed with "there ought to be" types of questions (e.g., there ought to be a vaccine) with broad acceptance and support.

The same cannot be said for the "what ought to be" research with wicked problems. Consider water management, where the old western saying of "Whiskey is for drinking and water is for fighting" highlights water management's wicked nature. An example of a "what ought to be" research question is: "What is the efficient reallocation of water among competing interests?" The implicit assumption is that efficient allocation is a policy goal, but policy goals do not emanate from disciplinary paradigms (Bromley 2008b; Stephenson 2003). As an approach to making policy decisions, "[the] rational analytic approach vests power and decision-making authority in the hands of unelected analysts" (Stephenson 2000, p. 11), thereby substituting the researchers' values of what is considered to be the best outcome for those of others. Also, the assumption of the linear model that all research will ultimately add value to decision making is flawed with wicked problems. Failure to recognize its inappropriate nature for wicked problems may account for much of the limited acceptance of such policy research (Batie 2005; Bromley 2008b; Shulock 1999). The assumption of "build it and they will come" is not appropriate; there is no assurance that the supply of knowledge about wicked problems (e.g., nature–human interactions) will have demanders.

Normal Science and Wicked Problems

Normal science is ill suited for wicked problems—with their attendant conflict over values and high uncertainty about system components and outcomes. By their nature, wicked problems cannot be easily categorized into separate disciplinary boxes nor can they be divided into more manageable parts under the assumption that there are clear and known casual paths (Weber and Khademian 2008). With wicked problems it is difficult to decide what facts to gather without first discussing values; thus, it is necessary not only to have many disciplines involved, but also to have interaction with those whose resources and cooperation are indispensable for tackling the problem—that is, with stakeholders (Bueren, Klijn, and Koppenjan 2003).

These various actors bring different values and perceptions to the policy dialog. For example, with respect to sustainability of ecosystems, environmental ethicists may focus on the intrinsic value of nature; applied economists may focus on the instrumental value of nature; and nonacademics may bring tacit knowledge garnered from practical experiences and personal values associated with nature and resource use (Norton 2005). Also, management agencies might consider natural resources from the viewpoint of wildlife survival, whereas project agencies might consider natural resources as commodities (Ingram and Bradley 2006). Even when dialog occurs and includes all of the actors, clear *solutions* rarely emerge; rather, via negotiation *processes* are identified which are judged as better or worse (not right or wrong) in addressing the wicked problem (Norton 2005).

Why the Concern About Wicked Problems Now?

Linear model and normal science were not challenged as long as society and policy makers felt that they were meeting social needs (Bonnen 1986; Pielke and Byerly 1998; Stokes 1997). But over the last several decades, that situation has changed. It is no longer widely assumed that scientific progress leads to societal progress (Frodeman and Holbrook 2007; Peters 2007). The reasons are multiple.

First, our improved understanding of system connections as well as recent volatility in natural resource and commodity prices has raised widespread concerns about the sustainability of many of our current development paths and practices (Millennium Ecosystem Assessment 2005). The complex connections between nature and society are seen as vulnerable. The warming of the global climate, for example, appears to be threatening the prosperity of economies as well as the functioning of ecosystems and the survival of many species. As more sustainability concerns arise, and as technologies appear to produce more risks than they resolve, many are challenging the post–World War II concept that our science can control the risks that it produces (Gallopin et al. 2001; Nowotny, Scott, and Gibbons 2001). Furthermore, the aforementioned critics note that science itself introduces new risks For example, the use of pesticides may reduce pest damage but may increase the risk of damages to human health (Russell 2001).

Gallopin and his colleagues (2001) note that what is at stake is not an admission of partial ignorance but rather the significance to be attached to the inability of science to exercise mastery over eventual outcomes. The earlier protection that provided science with the now questioned belief that more knowledge will reduce uncertainties, increase capacity for control of nature, and permit the remedying of past mistakes is stripped away—along with the "ideological privilege" that gave presumptive preference to the intended outcomes of scientific research while discounting any unintended side effects.

Second, wicked problems do not fit the linear model of science, which has smoothed over its wicked, rough edges with abstracting assumptions.[2] In ecosystem sustainability debates, for example, many question the assumptions that there are simple linear causes and effects of problems; science can control nature; the past is a good predictor of the future; or there are equilibrium conditions to which natural systems will return following disturbances. For sustainability issues, the alternate assumptions are that there is nonlinearity and unpredictability to system components; science cannot control the negative and cumulative effects of technologies on nature and society; and there are thresholds (e.g., tipping points) that can cause irreversible outcomes.

Thus, while normal science assumptions might have fitted well with earlier conservation practices of the progressive conservation period—when natural resources were viewed as commodities and there was considerable public consensus about the goals of resource management—that fit is no longer the case. Now, these assumptions are challenged in the age of environmentalism because ecosystems are assumed to provide many functions and services, including life support, and when there is considerable public conflict about which services are the most valuable and about how to practice environmental management (Batie, Shabman, and Kramer 1986; McCool and Guthrie 2001).

As a consequence, there is increasing dissatisfaction with curiosity-driven, disciplinary-based science. Criticisms abound with the "stove-piped" or the "silo" nature of the disciplinary approach for addressing wicked problems. As the old saying goes: "The world has problems, while universities have departments." It is becoming more evident that

[2] An example in applied economics would be the assumption that Pareto-irrelevant externalities (i.e., where there are no further gains from trade) should not be addressed by environmental policies (Bromley 2008a,b). As Bromley notes, labeling an externality as Pareto irrelevant implies that all costs of the status quo fall on the victims, who probably desire regulation to change that situation regardless of their ability to pay. Similarly, Norgaard (2002) argues that environmental problems are thought of as market failures when they more accurately could be considered to be evidence of the applicable limits of the market model.

normal science is inadequate in resolving wicked problems with their attendant conflicts over whose values will prevail in deciding (a) what future is desirable; (b) what trade-offs are worth making; and (c) who bears the costs or gains the benefits of decisions (Weber and Khademian 2008). When values are in conflict and when outcomes are of high consequence, but uncertain, or where there is significant scientific disagreement,[3] scientific experts are not allowed to dictate preferred policies (Fear et al. 2006). Indeed, if normal science is used to address wicked problems, the frequent result is controversy and gridlock (Pielke 2007; Sarewitz 2004). The decision of whose values count is made in the political world, not in the world of science (Bromley 1997).

Third, globalization has also challenged the monopoly of the western science's arbitration of what constitutes valid knowledge. Within policy discussion, there is broader acceptance of the experience of practitioners as tacit (e.g., silent) knowledge; there is more focus on unique local situations that contextualize knowledge, and there is inclusion of alternative knowledge as well as hybrid knowledge which combines various types of knowledge. The distinct boundaries between science and nonscience are dissolving to be replaced with a wider framework of sources of knowledge to inform policy (Nowotny, Scott, and Gibbons 2001).

Fourth, these challenges to normal science are enabled and reinforced by new ways of communicating among stakeholders that provide civil society low-cost access to a wealth of data and information as well as low costs to political organizing (Hawken 2007). Currently, for example, food companies are struggling with how to meet some consumers' demands for more sustainability attributes in their products and processes; they know that even small groups of consumers can effectively organize and communicate their concerns to others via the Internet[4] and impact company revenues, but the companies struggle to determine what they should do to profitably address the wicked problem of sustainability.

Addressing Wicked Problems

Society is changing what it is asking of science; as a result, the role of science in decision making is becoming quite complex (Pielke 2007). Addressing wicked problems in a policy context requires both use-driven science that recognizes and addresses uncertainties and meaningful engagement of stakeholders in decision making that propels knowledge into action. While science can offer new ways of thinking or catalyze new technologies, only changes in policies and management lead to action (Ingram and Bradley 2006). The latter requires engagement of stakeholders.

There is a large and growing literature about various approaches to postnormal science that addresses uncertainties (e.g., Funtowicz and Ravetz 1993; Nowotny, Scott, and Gibbons 2001). An example is the field of ecological economics (Funtowicz and Ravetz 1994), which has its own transdisciplinary journal and focuses on the human/nature nexus, frequently in a policy context. Ecological economics has a pluralistic but scientific approach to the study of environmental problems and policy solutions. It is characterized by systems perspectives and appropriate physical, biological, and social contexts as well as a focus on long-term environmental sustainability.

Another postnormal science example is complexity economics, some of which traces its roots to the Sante Fe Institute's exploration of relationships between economics and physics. Complexity economics is highly mathematical and statistical, and it focuses on complex adaptive systems in pursuit of "real world" relevancy. The core components of complexity dynamic models include the psychology of the economic agents, the process of learning, adaption to a changing environment, and coevolution processes. Complexity economics stresses nonlinearities, disequilibria, and path dependences[5] (Colander 2000). Both ecological economics and complexity economics emphasize postnormal science and assumptions but do not necessarily address engagement or policy applications.

Another postnormal science is that of sustainability science. It is highly integrated and

[3] For a good discussion of types of conflict in science in policy-making context, see Lord (1979).

[4] The uncertainties surrounding wicked problems can easily lead to the "scientization" of politics, where there is a selective use of scientific findings to support particular political positions, and where some scientists may become issue advocates (Pielke 2000; Sarewitz 2004). Sarewitz explores how to avoid such scientization via such means as articulating value positions from the beginning of a controversy. Scientization of politics further confuses the distinction between "is" and "ought" types of policy research and undermines the legitimacy of scientists in policy.

[5] As Brock and Colander (2000) write with respect to complexity economics, "Complexity . . . takes away the reference point for [economic] theory's defense of the market. In the complexity vision there is not proof that the market solves problems. There is not unambiguous way of stating what is and what is not an externality and there is no guarantee that the market leads to the most desirable equilibrium" (p. 82).

multidisciplinary; it has a direct focus on wicked problems (e.g., sustainable development) and includes engagement with stakeholders through such institutions as boundary organizations. Therefore, sustainability science is a good example to illustrate how science can address wicked problems in a policy context.

Sustainability Science

Sustainability science has emerged in the last two decades; it is defined by the problems that it addresses rather than the disciplines involved. It seeks to inform and facilitate a societal transition toward sustainable development (Clark 2007). It is integrative in that it is committed to bridging the communities engaged in promoting environmental conservation, human health, and economic development. It includes research knowledge from the natural, social, and engineering sciences with insights from the humanities. It also incorporates knowledge from those who move knowledge to action (Clark 2006). Thus, sustainability science needs to be engaged, since it is stakeholders who will help frame the problem, determine goals, and implement the desired change.

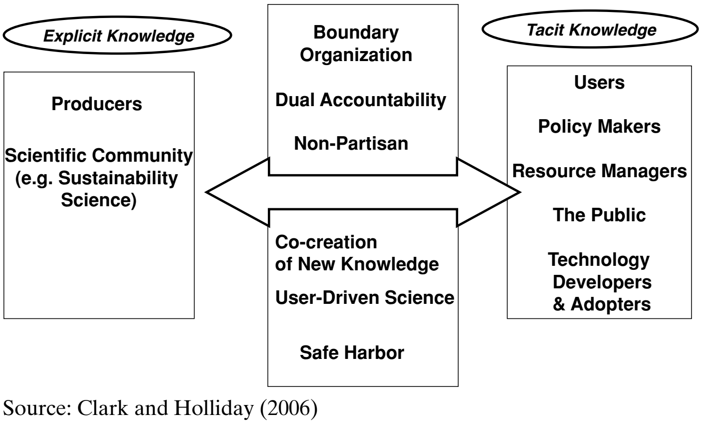
Thus, sustainability science, while still evolving, has become an integrated, multidisciplinary use-driven science that seeks to (1) analyze and predict the behavior, at multiple scales, of complex self-organizing systems; (2) identify and characterize the irreversible impacts of interacting stresses on such systems; and (3) assess the roles of people in the functioning of such systems (Cochran 2000). Central questions include the following: How can dynamic interactions be better incorporated into emerging models and conceptualizations that integrate the Earth system, social development, and sustainability? What systems of incentive structures can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories? (Bolin et al. 2000).

Engagement Using Boundary Organizations

Effective engagement of stakeholders is challenging (Jacobs, Garfin, and Lenart 2005; McDowell 2001). While there are resources that help to guide critical engagement, and extension faculty have been pursuing such engagement for decades, there remains more to learn (Fear et al. 2006).

One approach to critical engagement is the use of a boundary organization, which is a bridging institution which links suppliers and users of knowledge and recognizes the importance of location-specific contexts (Ruttan et al. 1994). As defined by Ingram and Bradley (2006): "Boundary organizations are situated between different social and organizational worlds, such as science and policy. According to advocates, boundary organizations succeed when three conditions are met. First, they must provide incentives to produce boundary objects, such as decisions or products that reflect the input of different perspectives. Second, they involve participation from actors across boundaries. Third, they have lines of accountability to the various organizations spanned [by the boundary organization] (Guston 2001). Adaptive and inclusive management practices are essential to the functioning of boundary organizations."

Figure 2 presents a figure of a boundary organization: on the left side is science and on the



Source: Clark and Holliday (2006)

Figure 2. Boundary organizations: Linking knowledge with action

right side are users of science. The boundary organization is used to link scientific knowledge (in this example sustainable science research) to the users. The arrow goes both ways because boundary organizations link those who have explicit knowledge, such as faculty, with those potential users of knowledge—such as resource managers, civil society, or policy makers—who have tacit knowledge garnered from experience.[6] Thus, a boundary organization by combining tacit and explicit knowledge can co-create new, transformational knowledge and shared understanding which may be critical to the innovation in the policy process (Conklin 2006; Guston 2001; Peterson 2008).[7] This cocreation process, by allowing participants to critically reflect on each other's views, enables participants to reflect not only on their own preferences and viewpoints but also on how they might be changed (White 1994).

Boundary organizations can function to reconcile supply and demand of existing knowledge; cocreate new knowledge; translate, negotiate, and communicate among the multiple parties on both sides of the science–use nexus; make transparent tacit assumptions and values embedded in models, paradigms, and assertions; identify uncertainties; seek alternative framing of problems; build hybrids (objects such as indicators or maps that contain both science and policy information); and build capacity to link knowledge to action (Miller 1999). In addition, boundary organizations can provide process accountability and "safe harbor" to all parties when there is serious conflict by functioning in a nonpartisan manner.

To illustrate how a boundary organization can function, consider the Arizona Water Institute (AWI).[8] As Ingram and Bradley (2006) note, water management disputes are not normally solved by the revealing of a scientific finding; rather, they emerge from negotiated consensus with water users and water managers. Thus, in addressing water management issues, the AWI combines the expertise of Arizona's water managers with over 400 water researchers at three Arizona universities; the Institute's mission is to support water resource management and technology development in real-world applications. The program includes stakeholder engagement and use-driven science in support of water management objectives as well as intermediaries who translate and connect science to users.

One method used is the formulating of scenarios of alternative water futures. Scenario work enhances integration across themes and serves as a mechanism for interdisciplinary work that engages stakeholders. With dynamic scenario development, alternative futures are identified (sometimes with forecast models), and then the analysis works backward in time to identify crucial pathways that avoid undesirable outcomes or result in desirable ones.[9] What is a desirable future is arrived at through a negotiated process among stakeholders.

The role of science is fundamental as a convening focus for AWI partnerships between faculty and water managers. In the language of boundary organizations, science can be a "boundary object" but only if a better understanding of physical and socioeconomic conditions is desirable from all parties' perspectives.

An illuminating outcome of AWI's approach is how engagement can change the identification and framing of problems. Prior to engagement of stakeholders in a science center associated with the AWI, faculty anticipated that the critical questions to be answered by water management research might be: (1) What are the costs and benefits of riparian preservation/restoration? and (2) What kinds of water markets and banking are feasible? Once the project commenced, it was determined that these were not key questions for water managers. Questions that emerged after discourse with managers were largely related to climate change and drought (Jacobs 2008). Sharing viewpoints and knowledge went both ways. For example, the faculty found that stakeholders did not always distinguish between important concepts such as weather and climate, nor between risk and uncertainty (Jacobs, Garfin, and Lenart 2005).

Linking insights and knowledge to action is a large challenge (Ingram and Bradley 2006; Jacobs, Garfin, and Lenart 2005; Stephenson and Shabman 2007); achieving and implementing a

[6] Explicit knowledge is that which is codified, rational, separable from context, and thus transmittable by formal means such as textbooks or manual. Tacit knowledge is context specific and informal arising from experience and practice (Peterson 2008).

[7] See Peterson (2008) for a discussion as to how this framework of the cocreation of transformational knowledge can be applied to supply chain and network performance management.

[8] For an excellent discussion of the history and use of another boundary organization, the California Bay Delta Authority, see Ingram and Bradley (2006). Jacobs, Garfin, and Lenart (2005) also provide a discussion of a climate-themed boundary organization in Arizona. Another boundary organization called *Oregon Solutions* is at Portland State University (http://www.orsolutions.org).

[9] Analogue scenarios are those which use similar situations (sometimes from the past) that shed light on future conditions (Jacobs, Garfin, and Lenart 2005).

negotiated consensus on which actions will be undertaken is a complicated process that takes time and resources (Jacob, Garfin, and Lenart. 2005). And as the scale of a problem expands to include regional, national, or global phenomena, the challenges become even larger (witness the Doha rounds in World Trade Organization negotiations!). However, the end result of using a well-functioning boundary organization can be a product that is distinctly different and more broadly accepted than would have emerged from either the researchers or the stakeholders if they operated independently (Ingram and Bradley 2006).

Engagement Methods

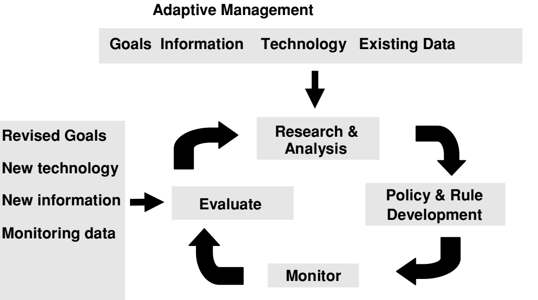
There are many engagement methods and techniques that can enhance engagement and link researchers with users. One technique is discourse[10] enabled by computer-aided dispute resolution models; another is the exploration of alternative policies as experimental case studies using adaptive management.

Discourse between stakeholders and researches can be added with computer-aided dispute resolution (Stephenson and Shabman 2007). These decision aids provide an approach to resource management decision making which engages stakeholders in a meaningful manner and manages (but does not avoid) conflict. The technical relationships of the model (traditionally the domain of modelers with the support of scientists) are jointly constructed with stakeholders. The involvement of stakeholders provides another way to verify technical relationships, level the technical playing field over diverse stakeholder interests, and build trust in science. The fact that there is some mechanism for collaborative model development sets computer-aided dispute resolution apart from the decision support literature which builds "user-friendly" models.

Computer-aided dispute resolution models have no single disciplinary focus, but they support negotiation among various stakeholders using computer simulation models. Their objective is not to simplify the range of choice, but rather they are used to separate arguments about "what is" from "what should be" across a broad range of potential choices. That is, the models are in service of decision making, and they are neither substitutes for the decision, nor the means of deciding. They are not decision models designed to maximize some goal; rather, they are used to fashion mutual understanding through discourse and are based on the premise that decision making is an iterative process with learning taking place as stakeholder preferences are developed or discovered when confronting choices (Stephenson and Shabman 2007). Stephenson and Shabman (2007) note that effective models are those that are credible, understandable, and useful to the decision participants and which avoid hiding or embedding those value judgments in the model that should instead be the appropriate domain of the discourse and collaborative negotiations.

Using policies as experiments (e.g., pilot programs) can be another way to address wicked problems. Consider environmental management of agricultural lands. Because system responses (including social systems responses) are fraught with uncertainties and significant unknowns (e.g., lags, thresholds, cultural influences) as well as confounding influences of spatial and temporal fluctuations and variability (e.g., climate changes, land use changes), no research can predict with certainty the results of large landscape changes on the environment or agricultural sector (Shennan 2008). Thus, there is a strong argument that policies should be viewed as experiments; basically they provide "learning by doing" but with extensive monitoring of environmental outcomes that then provides information for adaptive management (Watzin 2007). As illustrated in figure 3, adaptive management involves feedback loops.

In adaptive management when policy is implemented (frequently with experiments built



Source: Batie and Rose (2006).

Figure 3. Adaptive management

[10] White (1994), in an article entitled "Policy Analysis as Discourse," discusses three types of discourse: analytic, critical, and persuasive. Analytical discourse draws on multiple theories and data sources; critical discourse emphasizes critical reflection and links evidence to value discussion; and persuasive discourse focuses on the roles of ideas and persuasion by policy entrepreneurs.

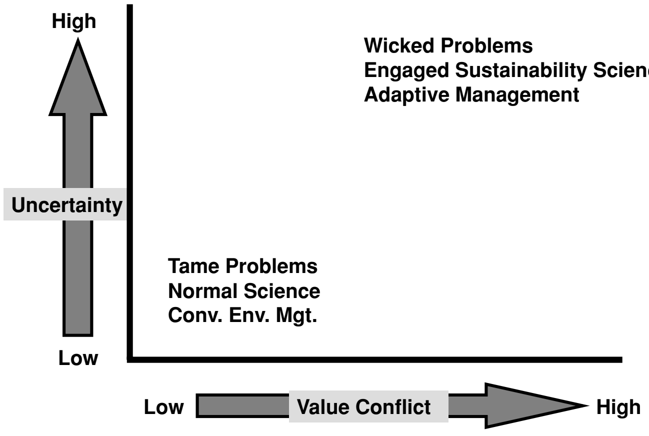


Figure 4. Wicked versus tame problems

into the policy design a priori), the results are monitored using key indicators as identified by stakeholders. These results are compared to the overarching goal(s) of the stakeholder-identified goals of the policy. If monitoring indicates that the goals are not being met, then additional research and stakeholder involvement is undertaken, and policy or goal adjustments are made. Adaptive management usually includes a close relationship between scientific research, managers, and local users of resources (Ingram and Bradley 2006; Norton 2005).

Figure 4 illustrates the differences, when addressing tame and wicked problems, between normal and postnormal science (e.g., engaged sustainability science) as well as the differences between conventional environmental management and adaptive management. Conventional environmental management refers to such issues as the cost-effective placement of riparian buffers and can be contrasted with adaptive management issues such as changes in whole watersheds to improve the survival of endangered migrating salmon.

Implications for Applied Economics

Should applied economics play a role in addressing wicked problems? There is little doubt that most wicked problems include issues of high consequence to society. The role that should be played by applied economics, however, depends on the nature of the subject matter boundary placed on the discipline. Yet, to exclude wicked problems risks the relevancy of applied economics.

The good news for those who view wicked problems as appropriate work for applied economics is that the integration of science into decision-making processes has expanded the roles for the social sciences. These demands for integrated, use-driven science are reflected in funders' requests for proposals (Moll and Zander 2006). Consider the National Science Foundation (NSF). At one time NSF's requests for proposals emphasized disciplinary-expanding, curiosity-driven basic research and arguably favored the biophysical sciences. Increasingly, the requests are for integrated, use-driven, multidisciplinary scholarship that includes social sciences. The NSF now lists social impact as a criterion for selection of projects along with scientific excellence and intellectual merit (Pielke 2007); if grant proposals fail to address the connection between the proposed research and its broader effects on society, they are returned without a review (Frodeman and Holbrook 2007). The Cooperative State Research, Extension, and Education Service (CSREES) of the U.S. Department of Agriculture, which manages the National Research Initiative, now requests specific proposals directed at perceived societal goals, such as small farm prosperity, that integrate many disciplines' research, outreach to and inclusion of stakeholders, and education. The committees of the National Academy of Science's National Research Council now include practitioners, private businesspersons, nongovernmental organization representatives as well as scientists.[11] Many federal regulations now require participation of both the general public and

[11] While it is not always obvious that those projects which excel at integration and engagement are always selected (Frodeman and Holbrook 2007), the trend is clear as to what is wanted. Presumably, the selection criteria will mature overtime to show even greater preference to excellent projects that are accountable to societal goals.

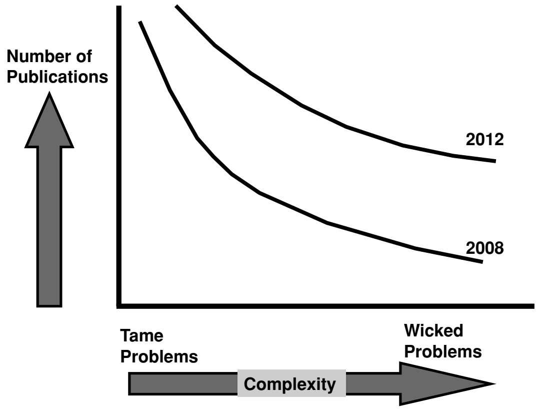


Figure 5. Shifting applied economics research toward wicked problems

agencies on federal projects; integrated assessments[12] are part of many federal programs (e.g., the U.S. Global Climate Change Research Program); and there are increasing congressional demands for greater accountability of federal science budgets to benefit society (Jacobs, Garfin, and Lenart 2005; Pielke and Byerly 1998; Shabman 2000; Stephenson 2000).

It is important to note that addressing wicked problems does not equate with abandoning normal science. Instead, it is an argument to allocate more of the discipline's resources to wicked problems. Consider figure 5,[13] where the number of publications is used to proxy the discipline's attention to societal problems. Assume that the curve labeled 2008 represents applied economists' current attention to tame and wicked problems. The shape of the curve reflects the large volume of applied economics articles that are about testing of theoretical propositions or disciplinary and method puzzle solving but which have little or no policy application as well as articles addressing tame problems. Also included are those articles which address wicked problems but reduce them to their reductionist components in a manner that inappropriately substitutes an analyst's decision for stakeholder-negotiated decisions. In contrast, there is a paucity of articles which appropriately address wicked problems and their complexities. The argument for more appropriate attention to wicked problems is an argument that the profession should shift the curve upward and to the right (e.g., to the one labeled 2012).

Many of the same tools and concepts used in addressing tame problems will be used in addressing wicked ones. Normal science can be used to address the "what is" and "what if" components of both wicked and tame problems. For example, participants in a negotiated process may want an applied economics analysis of, say, trade-offs associated with the selection of one policy alternative over another, so that the participants can decide what trade-offs are worth making, or they may desire a cost analysis for the implementation of alternative policies (Stephenson 2003). However, the value of such analysis is likely to be enhanced if it is undertaken after an exploration of values underlying the dispute are made transparent if their implications for society are explored and if suitable goals are identified (Sarewitz 2004).

On the other hand, the necessity for the cocreation of knowledge to address wicked problems challenges many of the assumptions of mainstream neoclassical economics, such as the argument that preferences and rational choice guide market choices, that the market is a mechanism for making social choices, that prices (market and nonmarket) equate with valuation, and that economic valuations can be mapped into what is socially preferred so that analysts can weigh competing alternatives and select the outcome that yields the highest societal benefits (Bromley 1997, 2006, 2008b; Funtowicz and Ravetz 1994; Shabman and Stephenson 2000; Stephenson 2000, 2003; Vatn and Bromley 1994).

Wicked problem analysis provides new opportunities for alternative methodologies, such as behavioral economics, Austrian economics, or original institutional economics. Consider, for example, the contributions to wicked problems that can be made from the methodology of original institutional economics—with its emphasis on processes as to how decisions are made via political negotiation approaches and how people behave under alternative institutions. Since addressing wicked problems involves improving negotiation processes (Norton 2005; Sarewitz 2004), original institutional economics has much to offer.

Other challenges associated with the cocreation of knowledge can emanate from differing disciplines' worldviews. For example, applied economists tend to have a greater faith

[12] Integrated assessment is a formal approach to provide comprehensive analysis of existing biophysical and social scientific information in the context of policy. Stakeholders (e.g., citizens, industry representatives, scientists, and policy makers) define and evaluate policy options for wicked problems.

[13] Thanks are due to Carol Shennan, Professor of Environmental Studies at University of California, Santa Cruz, who suggested this figure.

in innovation in the face of scarcity so that, say, environmental scarcity can be successfully overcome; many ecologists do not share that optimistic worldview (Norgaard 2002; Sarewitz 2004). Stakeholders, too, bring worldviews that can be in conflict with each other and with disciplines. Since there is much uncertainty about "facts," and therefore many competing alternative "futures" are supported by available knowledge, conflicts are inevitable. Defusing these conflicts will require that applied economists abandon any prescriptive certitude and disciplinary hubris they might have and engage in respectful discourse (Bromley 2006; Johnson 2007; Klamer 2007).

What Is Needed?

The types of skills that are needed to undertake such postnormal science activities are neither well taught in applied economics graduate programs, nor do they appear to be rewarded well in our research institutions. Necessary skills not only include the ability to respect and understand many perspectives and viewpoints but also skills in communication and translational science to translate existing scientific findings into a form suitable for practical applications (Batie and Rose 2006). There needs to be more study of and familiarity with the methods of effective engagement which would include the development of management and leadership skills that are able to incorporate and integrate the knowledge, skills, resources, and perspectives from many actors (Ingram and Bradley 2006). There needs to be a willingness and ability to understand the social and historical contexts surrounding policy formulation as well as how decisions are actually made (Batie 2005; Jacobs, Garfin, and Lenart 2005).

There also needs to be more research directed toward both understanding and facilitating collective decision making; actual preferences and preference formation; and identification of which held values are subject to change and which are core values which are not easily altered (Sabatier 1988). This research would need to involve other disciplines including psychology, decision science, and sociology.

More fundamentally, however, there is a need to understand that the role of the applied economist changes with the shift from tame to wicked problems. In applied economics, this change involves moving from a "pure" analyst to that of the honest broker[14] whose job is not to narrow the range of policy choices to the optimal one but rather to expand the range of choice (Pielke 2007). To do the honest broker role well, applied economists need to better understand the values and assumptions embedded in their particular methodological approach. They need to practice transparency in deliberative processes while maintaining scientific credibility.

All of these needed skills suggest that alternative methodologies and the history of economic thought should be taught in our graduate training and included in professional's continuing self-education. In a recent review of conversations with economic graduate students throughout the nation, Klamer (2007) lamented: "Particularly worrisome is the perception of this cohort of graduate students concerning the science of economics.... In contrast to their counterparts in the eighties, they do not question the scientific approach that they are learning and they do not wonder about alternatives. Modeling continues to be the way they go" (p. 230). He continues: "This cohort appears to be mindless, or at least resourceless, when it comes to reflections on the nature of their science. They have no literature to fall back on. Even the text of Milton Friedman appears to have dropped from their reading lists. (Needless to say, economic methodology has no place in the curriculum.) Apparently they are taught to do what they are doing without giving much thought as to the 'how so' and 'why questions'" (p. 231). As postnormal science evolves, Klamer's remarks about why economics as a discipline is at risk are worth consideration as well by applied economists. To paraphrase Klamer, how will applied economists fare in the company of other scholars who are so much more aware of developments in the new thinking about science?

Barriers to Remodeling

The barriers to such a remodeling of the applied economics discipline appear to be large.

[14] In an earlier work, Batie (2005) refers to this role as a science advocate (i.e., honest broker) who understands that to be effective there needs to be a commitment to learning about the art and craft of policy analysis: "Policy relevancy requires that the science advocate understand the policy in question, the issues of concern, and the institutions and stakeholders involved in the decision(s). This requirement suggests a considerable amount of effort by the analyst in understanding the history of the issues surrounding the policy, the motivation of the actors involved, and the policy process itself" (p. 128).

Our research institutions are not designed to reward engaged, integrated, multidisciplinary science activities well, although that may be slowly changing. However, many of the poorly aligned incentives or the research institutions are derivatives of the discipline's own viewpoint that there is no reason to change;[15] wicked problems can either be effectively addressed using the same methods and approaches as tame problems; or they are not an appropriate subject for the field. Other applied economists appear to be so constrained by their focus on end states such as optimization that they cannot constructively contribute to negotiated decision-making processes essential to effectively addressing wicked problems. Further, following the status relationship set forth within the linear model, many in the discipline continue to devalue engagement scholarship. Still, others may adopt a rational analytical method for policy analysis, even when doubting the utility or validity of the approach, because they perceive that it meets the disciplinary and institutional standards for objective science (Brunner 1991), whereas postnormal science draws on such a variety of methods and methodologies that are perceived to be more difficult to defend as well as to undertake. Therefore, not only do research institutions' incentives need to be realigned, so do the discipline's.

Until realignment happens, postnormal science scholarship and engagement of wicked problems will probably remain the task of a small set of applied economists who are willing to take on these wicked problems regardless of their colleagues' or institution's approval. But what are the consequences? One may well be that those prospective graduate students who see a value in applied economics addressing society's wicked problems may eschew applied economics for schools of public policy and decision science which provide education appropriate to their concerns. And this outcome is only one of the many ways that applied economics will suffer if it is labeled as irrelevant due to neglect of wicked problems or because wicked problems were treated as if they were tame.

[15] This attitude that there is no reason to change may have been reinforced with the last several decades' dominance of "free market" politics. The recent economic crisis may end that dominance as more regulation is imposed on markets.

Conclusion

There are many who believe that there is a renegotiation underway of the contract of society with science (Clark 2006; Frodeman and Holbrook 2007; Moll and Zander 2006; Shabman 2000; Sarewitz 2004; Stokes 1997); but there is little evidence that applied economics is fully cognizant of this renegotiation. This renegotiation provides opportunities and risks to the discipline.

Increasingly, the linear concept—in which more science leads to less uncertainty which leads to improved decisions—is viewed as flawed with respect to wicked problems. Thus, for applied economics, as well as other sciences, what is needed are new ways of thinking about the conduct of science; validating scientific contributions; developing institutions to facilitate engaged science–stakeholder processes (Sarewitz 2004); and embedding ways of thinking and methods into graduate education. The challenges are great, but so is the potential payoff. The important questions for applied economists to address are:

1. How does applied economics find its role in addressing wicked problems?
2. How does applied economics institutionalize processes (including graduate education) that are relevant to successfully fulfilling those roles?
3. How does applied economics survive and thrive if more resources are allocated to address wicked problems?

The alternative question also remains:

> How does applied economics survive, thrive, and maintain relevancy if it neglects wicked problems?

References

Batie, S.S. 2005. "The Demand for Economic Policy Analysis: Is Anyone Listening?" *Agriculture and Resource Economics Review* 34(2):123–30.

Batie, S.S., and J.B. Rose. 2006. "Environmental Issues and Water Resources." Paper presented at National Agricultural Research, Extension, Education, and Economics (NAREEE) board meeting, Washington, DC, 25 October.

Batie, S.S., L.A. Shabman, and R.A. Kramer. 1986. "U.S. Agricultural and Natural Resource Policy." In C.F. Runge, ed. *The Future of the North American Granary: Politics, Economics and Resource Constraints in American Agriculture*.

Ames, IA: Iowa State University Press, pp. 132–38.

Bolin, B., W. Clark, R. Corell, N. Dickson, S. Faucheux, G. Gallopín, A. Gruebler, M. Hall, B. Huntley, J. Jäger, C. Jaeger, N. Jodha, R. Kasperson, R. Kates, I. Lowe, A. Mabogunje, P. Matson, J. McCarthy, H. Mooney, B. Moore, T. O'Riordan, J. Schellnhuber, and U. Svedin. 2000. "Core Questions of Science and Technology for Sustainability." Available at http://sustsci.aaas.org/content.html?contentid=776 (accessed June 12, 2008).

Bonnen, J.T. 1986. "A Century of Science in Agriculture: Lessons for Science Policy." *American Journal of Agricultural Economics* 68(5):1065–80.

Brock, W.A., and D. Colander. 2000. "Complexity and Policy." In D. Colander, ed. *The Complexity Vision and the Teaching of Economics*. Cheltenham, UK: Edward Elgar, pp. 73–96.

Bromley, D.W. 2008a. "Institutional Economics as Volitional Pragmatism." In S.S. Batie and N. Mercuro, eds. *Alternative Institutional Structures: Evolution and Impact*. New York: Routledge, pp. 91–112.

——. 1997. "Rethinking Markets." *American Journal of Agricultural Economics* 79(5):1383–93.

——. 2006. *Sufficient Reason: Volitional Pragmatism and the Meaning of Economic Institutions.* Princeton, NJ: Princeton University Press.

——. 2008b. "The Emergence and Evolution of Environmental and Natural Resource Economics." In J. Wu, P.W. Barkley, and B.A. Weber, eds. *Frontiers in Resource and Rural Economics: Human-Nature, Rural-Urban Interdependencies*. Washington DC: Resources for the Future, pp. 11–28.

Brunner, R. 1991. "The Policy Movement as a Policy Problem." *Policy Sciences* 24:65–98.

Bueren, E.M., E.H. Klijn, and J.F.M. Koppenjan. 2003. "Dealing with Wicked Problems in Networks: Analyzing an Environmental Debate from a Network Perspective." *Journal of Public Administration Research and Theory* 13(2):193–212.

Bush, V. 1945. *Science—The Endless Frontier*. Washington DC: Government Printing Office.

Carroll, M.S., K.A. Blatner, P.J. Cohn, and T. Morgan. 2007. "Managing Fire Danger in the Forest of the US Inland Northwest: A Classic 'Wicked Problem' in Public Land Policy." *Journal of Forestry* 105(5):239–44.

Clark, W. 2006. "Sustainability Science: A Room of Its Own." *Proceedings of the National Academy of Sciences in the United States of America (PNAS)* 104:1737–38.

——. 2007. "Sustainability Science: An Emerging Interdisciplinary Frontier." *The Rachel Carson Distinguished Lecture Series*. East Lansing: Michigan State University.

Clark, W., and L. Holliday (Rapporteurs). 2006. "Linking Knowledge with Action for Sustainable Development: The Role of Program Management." Workshop Summary, Roundtable on Science and Technology for Sustainability Policy and Global Affairs. National Research Council of the National Academies. Washington DC: National Academies Press.

Cochran, S. 2000. "Sustainability Science: Statement of the Friibergh Workshop on Sustainability Science." Friibergh Manor, Orsundsbro Sweden, 11–14 October. Available at http://ksgnotes1.harvard.edu/BCSIA/sust.nsf/pubs/pub3/$File/FW_statement.pdf (accessed June 18, 2008).

Colander, D. ed. 2000. *Complexity and the History of Economic Thought: Perspective on the History of Economic Thought*. New York: Routledge.

Conklin, J.E. 2006. *Dialog Mapping: Building Shared Understanding of Wicked Problems*. Napa, CA: CogNexus Institute.

Fear, F.A., C.L. Rosaen, R.J. Bawden, and P.G. Foster-Fishman. 2006. *Coming to Critical Engagement: An Autoethnographic Exploration.* Lanham, MD: University Press of America.

Frodeman, R., and J.B. Holbrook. 2007. "Sciences' Social Effects." *Issues in Science and Technology* 23(3):28–30.

Funtowicz, S.O., and J.R. Ravetz. 1993. "Science for the Post-normal Age." *Futures* 25(7:)739–55.

——. 1994. "The Worth of a Songbird: Ecological Economics and Post-normal Science." *Ecological Economics* 10:197–207.

Gallopin, G.C., S. Funtowicz, M. O'Conner, and J. Ravetz. 2001. "Science for the Twenty-First Century: From Social Contract to the Scientific Core." *International Social Science Journal* 53(168):219–29.

Guston, D.H. 2001. "Boundary Organizations in Environmental Policy and Science." *Science, Technology and Human Values* 26(4):399–408.

Hawken, P. 2007. *Blessed Unrest: How the Largest Movement in the World Came into Being and No One Saw It Coming*. New York: Viking Press.

Horn, R.E., and R.P. Weber. 2007. *New Tools for Resolving Wicked Problems: Mess Mapping and Resolution Mapping Processes*. Watertown, MA: Strategy Kinetics L.L.C.

Ingram H., and B. Bradley. 2006. "Water Sustainability: Policy Innovation and Conditions for Adaptive Learning." Paper presented at the Michigan State University Sustainable

Michigan Endowed Project Academy, Dearborn, MI, 18–19 November.

Jacobs, K.L., G.M. Garfin, and M. Lenart. 2005. "More than Just Talk: Connecting Science and Decision Making." *Environment* 47(9):6–22.

Jacobs, K. 2008. "Informing Priorities for Water Sustainability Research Through Dialogues Between Decision Makers and Scientists." Paper presented at the Linking Knowledge with Action for Sustainable Development, Sackler Colloquium of the National Academy of Sciences, Washington DC, April 3–4.

Johnson, M. 2007. "Finding Peace for Economists in Universities." *Journal of Agricultural and Resource Economics* 32(3):417–24.

Klamer, A. 2007. "Does This Have To Be Our Future?" In D. Colander, ed. *The Making of an Economist, Redux.* Princeton, NJ: Princeton University Press, pp. 227–28.

Kreuter, M.W., C. De Rosa, E.H. Howze, and G.T. Baldwin. 2004. "Understanding Wicked Problems: A Key to Advancing Environmental Health Promotion." *Health, Education, and Behavior* 31:441–54.

Kuhn, T.S. 1962. *The Structure of Scientific Revolutions.* Chicago, IL: University of Chicago Press.

Lindbloom, C. 1965. *The Intelligence of Democracy: Through Mutual Adjustment.* New York: Free Press.

Lord, W.B. 1979. "Conflict in Federal Water Resource Planning." *Water Resources Bulletin* No. 5:226–1235.

McCool, S.F., and K. Guthrie. 2001. "Mapping the Dimensions of Successful Public Participation in Messy Natural Resources Management Situations." *Society and Natural Resources* 14(4):309–23.

McDowell, G.R. 2001. *Land-Grant Universities and Extension into the 21st Century: Renegotiating or Abandoning a Social Contract*. Ames: Iowa State Press.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis.* Washington DC: Island Press.

Miller, C.A. 1999. "Report of the Workshop on Boundary Organizations in Environmental Policy and Science." Bloustein School of Planning and Public Policy, Rutgers University, New Brunswick, NJ, December 9–10.

Moll, P., and U. Zander. 2006. *Managing the Interface: From Knowledge to Action in Global Change and Sustainability Science.* In S. Lindemann and P. Wood, trans. Munich, Germany: German Federal Ministry of Education and Research.

Norgaard, R.B. 2002. "Optimists, Pessimists, and Science." *Bioscience* 52(3):287–92.

Norton, B.G. 2005. *Sustainability: A Philosophy of Adaptive Ecosystem Management.* Chicago, IL: University of Chicago Press.

Nowotny, H., P. Scott, and M. Gibbons. 2001. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty*. Cambridge, UK: Polity Press.

Peters, S.J. 2007. "Changing the Story About Higher Education's Public Purposes and Work: Land-Grants, Liberty, and the Little Country Theater." *Imagining America*, Forseeable Futures Position Paper No. 6, University of Michigan, MI.

Peterson, C. 2008. "Transformational Supply Chains and the 'Wicked Problem' of Sustainability: Aligning Knowledge, Innovating, Entrepreneurship, and Leadership." Keynote address presented at the International Chain Conference, Wageningen, The Netherlands, 29 May.

Pielke, R.A., Jr. 2007. *The Honest Broker: Making Sense of Science in Policy and Politics.* Cambridge, UK: Cambridge University Press.

Pielke, R.A., Jr., and R. Byerly, Jr. 1998. "Beyond Basic and Applied." *Physics Today* 51(2):42–46.

Porter, T.M. 1995. *Trust in Numbers: The Pursuit of Objectivity in Science and Public Policy.* Princeton, NJ: Princeton University Press.

Rittel, H., and M. Webber. 1973. "Dilemmas in a General Theory of Planning." *Elsevier Policy Sciences* 4:155–69.

Russell, E. 2001. *War and Nature: Fighting Humans and Insects with Chemicals from World War II to Silent Spring.* Cambridge, UK: Cambridge University Press.

Ruttan, V.W., D.E. Bell, and W.C. Clark. 1994. "Climate-Change and Food Security—Agriculture, Health and Environmental Research." *Global Environmental Change-Human and Policy Dimensions* 4(1):63–77.

Sabatier, P.A. 1988. "An Advocacy Coalition Framework of Policy Change and the Role of Policy Oriented Learning Therein." *Policy Sciences* 25:237–54.

Sarewitz, D. 2004. "How Science Makes Environmental Controversies Worse." *Environmental Science and Policy* 7:385–403.

Shabman, L. 2000. "Bargaining, Analysis and Water Management." *Water Resources Update* 71, March.

Shabman, L., and K. Stephenson. 2000. "Environmental Valuation and Its Economic Critics." *Journal of Water Resource Planning and Management* November/December:382–88.

Shennan, C. 2008. "Biotic Interactions, Ecological Knowledge and Agriculture." *Philosophical*

Transactions of the Royal Society 363:717–39.

Shulock, N. 1999. "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):226–44.

Stephenson, K. 2003. "Environmental Goal Setting." In M.R. Tool and P.D. Bush, eds. *Institutional Analysis and Economic Policy.* Boston, MA: Kluwer, pp. 443–60.

——. 2000. "Taking Nature into Account: Observation About the Changing Role of Analysis and Negotiation in Hydropower Re-licensing." *William and Mary Environmental Law and Policy Review* 25:1–26.

Stephenson, K., and L. Shabman. 2007. "Overview of Computer-Aided Dispute Resolution: Approach and Evaluation." In K. Stephenson, L. Shabman, S. Langsdale, and H. Cardwell, eds. *Computer Aided Dispute Resolution: Proceedings from the CADRe Workshop*. Albuquerque, New Mexico. Available at http://www.svp.iwr.usace.army.mil/docs/SVP-2007-R-06.pdf (accessed July 12, 2008).

Stokes, D.E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation.* Washington DC: Brookings Institution Press.

Vatn, A., and D. Bromley. 1994. "Choices without Prices and without Apologies." *Journal of Environmental Economics and Management* 26(2):129–48.

Watzin, M.C. 2007. "The Promise of Adaptive Management." In M. Schnepf and C. Cox, eds. *Managing Agricultural Landscapes for Environmental Quality*. Ankey, IA: Soil and Water Conservation Society, pp. 147–58.

Weber, E.P., and A.M. Khademian. 2008. "Wicked Problems, Knowledge Challenges, and Collaborative Capacity Building in Network Settings." *Public Administration Review* 68(2):334–39.

White, L.G. 1994. "Policy Analysis as Discourse." *Journal of Policy Analysis and Management* 13(3):506–25.