Sustainability Science: A Call to Collaborative Action

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Sustainability science is an emerging field directed at advancing sustainable development. Informed by recent scholarship and institutional experiments, we identify key roles for economists and encourage their greater participation in this research. Our call to collaborative action comes from positive experiences with the Sustainability Solutions Initiative based at the University of Maine, where economists collaborate with other experts and diverse stakeholders on real-world problems involving interactions between natural and human systems. We articulate a mutually beneficial setting where economists' methods, skills, and norms add value to the problem-focused, interdisciplinary research of sustainability science and where resources, opportunities, and challenges from science bolster economic research specifically and land/sea grant institutions broadly.

Key Words: economics, interdisciplinary research, problem-solving, organizational innovation, stakeholders, sustainable development

Wicked Problems and Related Challenges

There is growing recognition that conventional approaches to the use of science in solving problems are inadequate for many complex societal challenges, including sustainable development to meet human needs while protecting the planet's life support systems (Holdren 2008, Lubchenco 1998, Lee 1993). Indeed, scholars have developed criteria for identifying problems that are especially resistant to traditional problem-solving strategies. Rittel and Webber (1973) introduced the term "wicked problems" to describe such challenges, suggesting that they can be characterized by multiple criteria, including problems that are difficult to define and delimit; problems that are symptoms of other problems; a collection of unique problems, which limits the potential for generalization; difficulty assessing the effectiveness of solutions;

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and the problems and their potential solutions are subject to divergent views among diverse stakeholders. Although Rittel and Webber focused primarily on problems related to social policy, their ideas have been applied to a variety of problems that have intersecting economic and ecological dimensions (e.g., Batie 2008, Waring 2012, Moser, Williams, and Boesch 2012).

In fact, scholars from disparate fields have converged in seeing a need for a paradigm shift in how researchers approach and help solve complex societal problems. Although these alternative approaches have unique labels such as wicked problems (Rittel and Webber 1973), post-normal science (Funtowicz and Ravetz 1991), and mode-two knowledge production (Gibbons et al. 1994) and differ in their details, they also have much in common. In particular, all of them seek to identify societal challenges associated with understanding and solving complex systems problems for which scientific knowledge is necessary but not sufficient and then to respond to such challenges more effectively. These alternative conceptual frameworks for addressing difficult societal challenges have also helped shape the field of sustainability science (Kates et al. 2001).

The Emerging Field of Sustainability Science

Although sustainability science has deep and diverse roots (National Research Council (NRC) 1999, Kates et al. 2001, Kates 2011a, 2011b, Bettencourt and Kaur 2011), its development was profoundly shaped by two key papers. First, a report by the World Commission on the Environment and Development (1987) introduced the term "sustainable development" to characterize the challenge of balancing human well-being and environmental protection. The report succinctly described sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Second, Kates et al. (2001) described the principal characteristics and foci of sustainability science and explained how this new field could be used to advance both the theory behind and the actual practice of sustainable development. In particular, they articulated seven core questions of sustainability science (see Table 1). Collectively, these essential questions encourage social scientists, natural scientists, and many others to work collaboratively and to improve how human-nature interactions are conceptualized, modeled, monitored, and evaluated. While this framing offered an invitation to scholars from many fields, it was evident that economists had much to contribute to this burgeoning research program, which stressed the importance of understanding the dynamics of nature-society interactions, the consequences of incentive structures, and the potential of incentive structures and monitoring and reporting systems to foster adaptive management and social learning.

As expected for any relatively new field of science that seeks to integrate so many different components and disciplinary perspectives, there has been considerable debate about exactly what sustainability science is, what it is not, and whether it can be made operational (Kates et al. 2005, Norton 2005, Norton and Toman 1997). Rather than focusing on those debates, however, we prefer a less formal conception of sustainability science as a type of systems thinking focused on connections between human well-being and ecosystem health, the present and the future, local and global scales, theory and practice, and knowledge and action (NRC 1999, Miller 2012). How does one know sustainability science when one sees it? Informed by preceding research (Clark et al. 2011, Levin and Clark 2010, van Kerkhoff and Lebel 2006, Clark and Dickson 2003), we recognize sustainability science as science that (i) is problem-driven and focused on deriving and testing solutions based on scientific knowledge, (ii) emphasizes the dynamic, coupled interactions between natural and human systems, and (iii) stresses active and ongoing engagement with diverse stakeholders.

Sustainability science has grown rapidly as a field of inquiry. One indication of its remarkable growth is that more than 20,000 publications on the subject have emerged, along with more than 21 million internet-based documents (Bettencourt and Kaur 2011). Other signs of acceptance include creation in the last decade of a new section on sustainability science in the *Proceedings of the National Academy of Sciences* (*PNAS*). That section joined established sections such as physics, engineering, and economics. Indeed, more than 350 research papers have now been published in this new section of *PNAS*. The National Science Foundation (NSF) is aiming to invest nearly $1 billion in its new Science, Engineering, and Education for Sustainability (SEES) Program, a portfolio of interdisciplinary activities that span a broad range of NSF directorates

Table 1. Core Questions of Sustainability Science

1. How can the dynamic interactions between nature and society—including lags and inertia—be better incorporated in emerging models and conceptualizations that integrate the earth system, human development, and sustainability?

2. How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?

3. What determines the vulnerability or resilience of the nature-society system in particular kinds of places and for particular types of ecosystems and human livelihoods?

4. Can scientifically meaningful “limits” or “boundaries” be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?

5. What systems of incentive structures—including markets, rules, norms, and scientific information—can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?

6. How can today’s operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?

7. How can today’s relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning?

Source: Kates et al. (2001).

(Killeen, van der Pluijm, and Cavanaugh 2012). Academic programs focused on sustainability (e.g., graduate and undergraduate degrees and certificates) are expanding rapidly at colleges and universities around the world (Association for the Advancement of Sustainability in Higher Education (AASHE) 2012, Wiek, Withycombe, and Redman 2011).

While the rapid growth in scholarship and educational activities is encouraging, it also raises questions about how, and whether, to manage the growth so that it contributes to increased understanding and leads to improved "real world" outcomes. What fields and institutions are well suited to participate in and foster advances in sustainability science while also benefitting from growing research funds and publishing opportunities? Our experience with a large project at the University of Maine has given us a unique perspective from which to describe and assess recent developments in the field (see the special issue of *Maine Policy Review* (2012) for more details about this NSF-funded project) and to explain why we see a need for increased participation by applied economists in this and other sustainability science research programs. We believe that economists' frameworks, research methods, conventions, norms, and skills make them particularly well suited to contribute to research in sustainability science. Moreover, we are encouraged by the potential for land and sea grant institutions, the home of many applied economists, to contribute to and benefit from advances in such collaborative research.

Sustainability Science in Practice

We view the practice of sustainability science in addressing complex problems as a three-part strategy: (i) problem-driven, solution-oriented scientific research, (ii) interdisciplinary research on dynamic interactions between natural and human systems, and (iii) efforts to engage stakeholders.

Problem-driven, Solution-oriented Science

The central purpose of sustainability science is not just to analyze problems but to contribute to solving them. Consequently, the goal is to blend the strengths of basic science and applied research (Clark and Dickson 2003). Sustainability science aims to understand and improve connections between scientific knowledge and societal actions by designing better processes for determining which research questions are relevant and by obtaining useful answers. Thus, developing and testing strategies that can improve the match between the demand for scientific information by society and the knowledge supplied by researchers are central goals (van Kerkhoff and Lebel (2006), Pielke and Sarewitz (2007), McNie (2007), Smith (2013); see Smith's article (in this volume) for an excellent discussion of such matching strategies). Over the past decade, researchers have reviewed existing studies of real-world sustainable development problems in terms of knowledge systems and found that many studies failed to meet the needs of decision-makers and other key stakeholders (Cash et al. 2003, Jasanoff 2004, van Kerkhoff and Lebel 2006, Clark et al. 2011, Smith 2013). The reviews also offered suggestions for how to improve collaboration between stakeholders and researchers and ways for all involved to use scientific information more effectively.

The degree of alignment between research questions and real-world problems, constraints of stakeholder's and researcher's time, and knowledge available from experts and the community can have a dramatic impact on the ability to connect scientific knowledge with societal action. Effective strategies for achieving those connections vary according to the context of each situation; researchers and stakeholders are jointly responsible for the performance of these knowledge systems. Under the knowledge-system framework, sustainability science becomes a mechanism to improve the performance of the "market" for scientific knowledge. Concurrently, sustainability science creates opportunities for economists to investigate the properties of that market and design and test interventions to improve its performance.

Interactions between Natural and Human Systems

Interactions between nature and society are the heart of the sustainable development challenge (and other natural resource management challenges), so it is obvious why sustainability science is focused on the dynamics of coupled natural and human systems (also called social-ecological systems). Understanding the dynamics of coupled systems requires attention to nonlinearities, feedbacks, and potential emergent properties (Ostrom 2009, Liu et al. 2007a, 2007b, Folke et al. 2005). This kind of research requires extensive interactions between social scientists and natural scientists and creates substantial opportunities for collaboration between economists and ecologists in particular. In theory, researchers from these two fields should have a lot in common given that the names of the two disciplines share the Greek root *oikos*, reflecting their joint focus on "the house." In practice, such collaboration does not always come easily. Indeed, it sometimes appears that economists and ecologists occupy entirely different houses that may or may not be located on the same planet (e.g., Roughgarden 2001, Norton and Toman 1997, Bockstael 1996). Fortunately, progress has been made in recent years as the two fields worked together on systems for modeling challenges (e.g., Bockstael 1996), analyses of policy and management (e.g., Swallow 1996), and integration of research themes such as ecosystem services (e.g., Daily et al. (2009), Boyd (2013), and others in this special issue). From sustainability science we gain new opportunities and incentives for greater and more productive collaboration among economists, ecologists, and researchers from many other fields of social science, natural science, and engineering.

Stakeholder Engagement

Stakeholder engagement is a cornerstone of sustainability science. Consistent with its focus on problems and orientation toward solutions, sustainability science pushes researchers to work collaboratively with every individual and organization with a stake in the outcome. Recognizing the potential for mismatches between knowledge supply and demand, scientists are encouraged to include stakeholders when they define problems, design research agendas, develop information, and suggest workable solutions. This co-production process has potential not only to align the research with stakeholders' concerns but also to enhance stakeholders' understanding of and trust in the research process and products (e.g., Cash et al. 2003, van Kerkhoff and Lebel 2006). A growing number of studies (e.g., Clark et al. 2011, NRC 2008, van Kerkhoff and Lebel 2006, Cash et al. 2003, Jacobs 2002, Jacobs et al. 2010) have examined stakeholder engagement and scientific processes, and they offer valuable guidance on how the effectiveness of different engagement strategies varies depending on the context of the sustainability problem. Because of its emphasis on diverse forms of engaged scholarship, sustainability science rewards institutions and fields that have established networks of stakeholders and conventions for conducting policy-oriented research. Sustainability science thus aligns well with the mission and expertise of land and sea grant institutions. Furthermore, economists at those institutions are often particularly suited to working with stakeholders because of the missions, cultures, networks, and reward systems within those institutions.

Researchers who endeavor to provide solutions to societal problems inevitably work within and across multiple boundaries. Thus, efforts to implement the three-part strategy for sustainability science research (i.e., problem-driven, solution-oriented scientific research; interdisciplinary research on dynamic interactions between natural and human systems; and efforts to engage stakeholders) can benefit from the diverse body of scholarship related to the concept of boundary management (Guston 2001, Jasanoff 1987). Boundary management refers to processes that mediate boundaries, including those that distinguish disciplinary fields, demarcate university and community relationships, shape partnerships between universities and the private sector, distinguish scientists and stakeholders, and divide scientists and the public (Smith 2013). Boundary management is central to many core functions of sustainability science research: engaging with stakeholders, selecting problems on which to work, studying coupled natural and human systems, and identifying potential solutions. Recent scholarship associated with sustainability science has drawn from the foundational literature on boundaries to stress how boundary "work" by researchers and others applies to deriving solutions to sustainability challenges (Cash et al. 2003, Clark et al. 2011). Collectively, those studies stress the importance of scientific efforts that are salient, credible, and legitimate; that emphasize scholarship that engages stakeholders and researchers in collaborative work to address problems; and that carefully consider contextual factors when choosing how to manage boundaries. Our experience to date suggests that applied economists possess methods, conventions, and networks that can facilitate their roles in boundary management. We recognize, however, that the institutional culture in which economists are employed, trained, and mentored has a significant influence on the incentive for this type of work.

Implementing Sustainability Science Research Initiatives

In response to the challenges and opportunities associated with solving sustainability problems, universities and colleges around the world have initiated programs in this area (Wiek, Withycombe, and Redman 2011, AASHE 2012). Among them are major institutional transformations, such as the creation of the Global Institute of Sustainability at Arizona State University (ASU). The institute serves as the hub for ASU's campus-wide focus on sustainability challenges (http://sustainability.asu.edu/index.php). Many other institutions of higher education have created new interdisciplinary centers and institutes, such as University of Minnesota's Institute on the Environment (http://environment.umn.edu), University of Washington's College of the Environment (http://coenv.washington.edu), and University of Delaware's Delaware Environmental Institute (http://denin.udel.edu).

Maine's Sustainability Solutions Initiative

We are part of a team of leaders at Maine's Sustainability Solutions Initiative (SSI), which is increasing the capacity of universities and colleges to solve pressing problems that have intersecting economic, social, and ecological dimensions (www.umaine.edu/sustainabilitysolutions). Supported in part by a major NSF EPSCoR (Experimental Program to Stimulate Competitive Research) grant, SSI has mobilized expertise from the majority of Maine's institutions of higher education to facilitate development of workable solutions. SSI currently includes more than 100 faculty members drawn from 30-plus disciplines that represent the natural sciences, social sciences, and engineering. Indeed, more than half of these faculty members are social scientists, including ten economists. SSI has more than 160 stakeholder organizations as partners, including federal, state, and local governments, tribal communities, the private sector, and nongovernmental organizations. The initiative manages a portfolio of 15-plus place-based research projects that focus broadly on problems related to landscape dynamics, including issues involving urbanization, forest management, climate change, and alternative energy. Economists at multiple institutions have assumed leadership roles on many SSI research projects.

We treat our set of Maine-based projects as a research portfolio and are conducting comparative studies of the projects to develop general principles regarding the organization and practice of sustainability science. SSI project teams were formed in response to a process in which research proposals were solicited. The request for proposals for place-based projects included incentives for incorporating several key design principles: (i) engagement with stakeholders to jointly define problems, define research strategies, and identify potential solutions, (ii) mobilization of interdisciplinary research teams that match the problems/solutions and can model interactions between human and natural systems, (iii) a commitment to creating durable researcher-stakeholder partnerships, and (iv) a focus on research that generates knowledge and advances solutions. Overall, our program provides widespread support for interdisciplinary, policy-relevant research and encourages innovation and risk-taking. Social science researchers with expertise in organizational science, organizational communication, social psychology, and economics are tracking and studying our performance on a range of activities. The goal of this research is to ensure that SSI's "whole is greater than the sum of its parts" and to inform the design of institution-wide research initiatives in sustainability science at other universities. For example, SSI organized a symposium ("What are the roles of knowledge institutions in sustainability?") at the 2013 meeting of the American Association for the Advancement of Science. The symposium included presentations by six academic leaders from across the United States who are immersed in, and learning from, novel institutional strategies for solving pressing sustainability problems. To date, SSI's accomplishments include playing a key role in developing innovative legislation, producing decision-support tools, advancing alternative energy technologies, building social capital, and training a new, more nimble generation of sustainability researchers and practitioners (e.g., Hart and Calhoun 2010, McCloskey et al. 2011, McCoy and Gardner 2012, Bell et al. 2013, Jansujwicz et al. 2013, Lyons et al. 2013).

Based on our prior experience at four other land grant universities, as well as at an Ivy League university and two liberal arts colleges, we believe that the

University of Maine has several characteristics that favor this kind of innovative research. Among them are an unusually strong land grant ethic in serving Maine's needs; a reduction of barriers to interdisciplinary collaboration that are related to institutional size, resources, and location; close and productive relationships with diverse stakeholders throughout the state; an entrepreneurial culture that facilitates innovation; and an individual and institutional humility that values diverse perspectives and pragmatic approaches to problem-solving.

Sustainability Science: Barriers and Opportunities

By definition, sustainability science includes both the challenges and the opportunities associated with conducting scientific research that is problem-driven, solution-oriented, interdisciplinary, and stakeholder-rich. Combining this orientation with the daunting class of societal problems that drove its inception engenders both caution and inspiration in researchers and policymakers. The evolution and impact of this field will depend strongly on how participating researchers, journals, and affiliated institutions negotiate these competing forces.

The structure of professional reward systems for researchers often drives them to produce knowledge of interest to their peers rather than of value to society (Brewer 1999, Matson 2009). Traditional sources of academic expertise can be highly compartmentalized, preventing them from producing an integrated understanding of real-world problems (Matson 2012, Robinson 2008). Meanwhile, problem-driven, solution-oriented research has long invoked mixed reactions from scholars in different fields. We do not expect institution-wide changes in reward systems, research units, or research processes. Rather, we anticipate institutional changes that reward a subset of faculty for taking on different research roles and that provide the research infrastructure necessary for faculty and students to take up collaborative research activities. The extent to which these changes occur will depend on the presence of incentives, such as recent shifts in institutional accountability metrics that emphasize influential research and training, increases in external funding for interdisciplinary research, and more emphasis given by funding agencies to projects that have broader societal benefits.

By its emphasis on the dynamics of coupled natural and human systems, sustainability science confronts the strengths and weaknesses of interdisciplinary research and education (National Academy of Sciences 2005), placing it squarely within an ongoing debate about the structure of universities (Whitmer et al. 2010). Given the multifaceted nature of sustainability problems and the diverse kinds of knowledge needed to solve them, successful sustainability science critically depends on effective interdisciplinary teamwork. This in turn requires the ability to meld diverse forms of knowledge—both disciplinary expertise representing biophysical and socioeconomic dimensions of real-world problems and traditional knowledge held by local communities and practitioners—and to mobilize that expertise in the search for solutions. Although universities and other research institutions often struggle to foster interdisciplinary teamwork, a growing body of research has identified best practices for building interdisciplinary capacity (Rhoten and Parker 2004, National Academy of Sciences 2005, Fiore 2008, Page 2008, Robinson 2008, Pohl 2011, Whitmer et al. 2010, McCoy and Gardner 2012). Such practices include various changes in institutional incentives, such as promotion and tenure criteria that reward a focus on solving real-world problems, creation of interdisciplinary centers and institutes that encourage team-based research, and mentoring processes that help researchers cross disciplinary boundaries. Differences in methodologies and styles of communication among members of interdisciplinary teams can create additional demands on the time and energy of researchers and impose a longer lag between researcher input and outputs. Conversely, when a project successfully couples natural and human systems, it produces rich opportunities for scholars to publish, acquire funding, and partner with stakeholders as faculty members from distinct disciplines tap into interdisciplinary and stakeholder networks. Without change in professional reward systems, participation in such research activities may be viewed as risky by junior faculty members and viewed skeptically by senior faculty members. Yet, the dramatic increase in interdisciplinary research and education units at universities and colleges, including those with sustainability in their names, offers hope for change in such reward systems (Pielke, Sarewitz, and Dilling 2010, Jacobs 2002). Few institutions are better positioned than universities to deliver on interdisciplinary approaches and sustainability problems given their diverse pools of expertise, their role in training future generations, their ties to local communities, and their potential to serve as a source of credible and objective information.

Sustainability science's focus on solutions and support for stakeholder engagement as integral to the research process also introduces both barriers and opportunities. In fact, the concept of a scientific solution is nearly as ambiguous as sustainability itself. No two problems are exactly the same, which precludes one-size-fits-all solutions and emphasizes the need for context-dependent knowledge and relationships tailored to specific places and processes. Moreover, the high degree of scientific uncertainty about the behavior of complex natural-human systems can hamper efforts to diagnose sources of problems and identify effective solutions (Rittel and Webber 1973, Ackoff 1981, Funtowicz and Ravetz 1991). A focus on solutions coupled with extensive engagement activities can intensify tensions that naturally exist between researchers and stakeholders. Differences in time horizons, schedules, communication styles, and research methods can thwart shared expectations about the timing, design, and implementation of a "solution" (Pielke, Sarewitz, and Dilling 2010, Jacobs 2002). Academic research is often isolated from the communities, decision-makers, and other stakeholders that are affected by real-world problems, which reduces the chances of arriving at a shared understanding of those problems and a commitment to the joint development of solutions. However, even when a sustainability project is not completely successful, it can provide a foundation for strengthening collaboration between academic researchers and stakeholders. In addition, its emphasis on solutions can create novel partnerships within institutions as faculty members from solution-focused divisions, such as sea grant and cooperative extension units, collaborate with faculty members from more traditional units.

We posit that certain educational institutions and academic disciplines are better suited to navigate the challenges and opportunities of sustainability science. Institutions with established track records in conducting collaborative research with external partners, such as land and sea grant institutions, have both vital experience and existing networks on which to build. Institutions that encourage cross-unit and interdisciplinary research and teaching activities are likely to complete such projects more cost-effectively and therefore gain greater net returns from experiments with sustainability science. Similarly, academic disciplines that employ systems thinking, address real-world problems and solutions, focus on interactions between society and the environment, and value basic and applied research are well suited for sustainability science research. For these and other reasons, we believe that economists can and should play key roles in sustainability science.

Key Roles for Economists in Sustainability Science

The training, skills, and conventions of applied economists uniquely position them to contribute to sustainability science because (i) economists have constructive conventions and frameworks for conceptualizing, conducting, and implementing problem-focused research; (ii) economists have valuable skills that can bring together, manage, and lead interdisciplinary research teams; (iii) sustainability science aligns well with the mission of land and sea grant institutions, home to numerous applied economics units; and (iv) sustainability science is a growing area that is generating a significant amount of research funding, publishing opportunities, broad societal impacts, and scientific challenges. In short, we see a mutually beneficial research setting in which economists have "wicked good" training to take on wicked problems and sustainability science has much to offer to economists.

The skills and research questions associated with applied economics and the scope and objectives of sustainability science generally align very well. We present an informal definition of sustainability science as a systems approach to connections between human well-being and ecosystem health, the present and the future, local and global scales, theory and practice, and knowledge and action. Economics training emphasizes all of those connections and imparts researchers with systems-thinking and modeling skills. Moreover, most applied economists conduct problem-oriented research and engage in some fashion, albeit sometimes a limited one, with stakeholders. Land grant experiment stations and professional networks for applied economics have forged enduring collaborations with decision-makers. Finally, the seven core questions of sustainability science (Table 1) point to opportunities for significant contributions by economists. While economic science is already contributing to our understanding of dynamics of coupled natural and human systems, incentive structures, information systems, adaptive management, and social learning, there is ample room for greater participation by economists in sustainability science.

Economists also may be well suited to serve in leadership and management roles on sustainability science projects. Why? Economists have at least wrestled with ways to operationalize the concept of sustainability (Howarth 1997, Norton and Toman 1997). More importantly, they are comfortable with system views, tradeoffs, and uncertainties. They have the skills needed to guide and support research and processes linked to all three parts of sustainability science's strategy for addressing complex problems. Admittedly, their success may be tempered by their willingness to collaborate with members of other fields, especially fellow social scientists with different epistemologies and research methods, and potentially by their ability to respond productively to colleagues who doubt their capacity to take on social problems.

Another key potential role for economists in sustainability science is as methodological leaders. We believe economists offer a valuable toolkit that matches well with the demands and domain of sustainability science. Economists have made significant contributions to the study of coupled natural and human systems, particularly by addressing how socio-economic factors both respond to and shape biophysical processes and patterns (e.g., Albers and Robinson 2011, Caviglia-Harris and Harris 2011, Lichtenberg 2011, Roy et al. 2010, Nelson et al. 2008, this special issue of *ARER*). The field's emphasis on quantitative methods, including both time-series and cross-sectional analyses, complements the variable scales and system interactions of sustainability challenges. Moreover, economists' experience working creatively with large and messy data sets to model human behavior at micro and macro scales prepares them for the difficulties of monitoring and modeling complex human-environment interactions. In addition, economists have considerable experience performing sophisticated analyses to examine how policy interventions, information systems, and broader incentive structures have affected or could affect individual and institutional decision-making. Economists experienced with survey research and trained in experimental economics add significant value to efforts to model human dynamics or evaluate project and team success. Our experience suggests that survey efforts and laboratory and field experiments are promising ways for scholars from different fields to collaborate. Success as a methodological leader will vary with scholars' abilities to share with and learn from colleagues.

The conventions of applied economics make economists well suited for more targeted roles in sustainability science projects. Their field's perspective and land grant ties are likely to mitigate aversions to problem-driven and solution-oriented science. As noted previously, applied economics has established strong norms that encourage researchers to work on real-world problems and to think carefully about describing policy and societal implications. Hence, applied economists may have a comparative advantage when serving as principal investigators for specific projects because of their ability to frame and design sustainability research projects to address problems. An interest in research that identifies causality and familiarity with quantitative approaches may help economists serve as project evaluators. Research aimed at studying the effectiveness of projects and connections between the knowledge generated by projects and the actions of individuals and institutions (Cash et al. 2003, Clark et al. 2011) can easily be framed using applied micro-economic theory.

Concluding Remarks

Despite the difficulties inherent in defining both the complex concept of sustainable development and the strategies and goals of sustainability science, we are convinced that science has a valuable role to play in navigating the sustainability transition. Much remains to be learned about how science can best contribute to a deeper understanding of sustainability and to improved policies and practices, but already we can identify several promising approaches. First and foremost, increasing value is being placed on science that is responsive to societal concerns and needs, underscoring the importance of engaged research with diverse stakeholders. Second, science is focusing greater attention on real-world problems and placing greater emphasis on developing workable solutions. Third, many real-world problems are characterized by intertwined economic, social, and ecological dimensions that underscore the benefits of integrating diverse forms of disciplinary and local knowledge to improve our ability to understand and manage dynamic society-environment interactions. Thus, efforts to promote sustainable development challenge scientists to focus on complex problems and employ research strategies based on these innovative principles.

Almost by definition, sustainability problems are messy, as is the science needed to solve them. Nonetheless, our experience suggests that sustainability science can be an intellectually challenging and personally rewarding endeavor. We believe that the skills, methods, and norms of applied economics uniquely position economists to assist in understanding and solving such problems. We see great potential for a mutually beneficial research setting in which (i) the frameworks, conventions, and skills of economists add great value to the problem-focused and interdisciplinary research of sustainability science and (ii) the resources, opportunities, and scientific challenges made available by sustainability science bolster economic research specifically and land and sea grant institutions broadly. We extend a call to collaborative action with the hope of changing the practices of science, the organization of universities, and the processes that link knowledge and action.

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