Environmental Economics: How Agricultural Economists Helped Advance the Field

Catherine L. Kling, Kathleen Segerson, and Jason F. Shogren

In this essay we examine the coevolution and cross-fertilization of environmental and agricultural economics over the past century. We discuss the key role that agricultural economists have played in the intellectual development of environmental economics. We focus on three primary contributions: incentive design, nonmarket valuation, and joint determination. The nature of these contributions is illustrated using specific examples from the literature. Agricultural economists' tendency to focus on applied problems has enriched and broadened both the academic debates and the policy advice provided by economists.

Key words: environmental economics, history of economic thought, incentive design, nonmarket valuation, joint determination.

JEL Codes: Q2, Q5.

"The power of population is indefinitely greater than the power in the earth to produce subsistence for man." Thomas Malthus
"Yes, I am the Lorax who speaks for the trees, which you seem to be chopping as fast as you please. But I'm also in charge of the brown Bar-ba-loots, who played in the shade in their Bar-ba-loot suits and happily lived eating truffula fruits. Now, thanks to your hacking my trees to the ground, there's not enough truffula fruit to go 'round!" Dr. Seuss, *The Lorax,* 1972.

Thomas Malthus and Dr. Seuss seem an odd pair to quote in a brief essay on the history of environmental economics as viewed through an agricultural lens. Yet their lives and the topics of their writings bracket the coevolution of environmental and agricultural economics over the past 100 years. In Malthus's lifetime, nature dominated humanity. Fundamental environmental questions were related to how people could best harness nature to meet basic human needs like food and shelter. The struggle for daily existence left little time for nature appreciation or outdoor recreational pursuits. Finding methods for more cost-effective agricultural production was the primary challenge. In contrast, by the time Dr. Seuss wrote *The Lorax* in 1972, humans in the developed world had "mastered" the environment to meet basic needs, and agricultural production was meeting the demand for food in most parts of the world. However, many observers were alarmed at the price of controlling nature, namely, the large-scale change in the quality and quantity of the natural environment, and its ability to supply clean water, air, and a variety of ecosystem services, such as outdoor recreation, biodiversity, aesthetic values, and wildlife habitat. Now the challenge became finding new cost-effective methods to achieve a joint goal—to meet our basic needs for food and shelter while simultaneously protecting the environment.

Looking back from our vantage point of today, we should not be surprised to find that major elements within environmental economics emerged from the tradition of agricultural economics. Agricultural economists interested in helping the world feed itself would have been exposed to loud concerns about how these efforts also impose substantial external costs on the environment.

Catherine Kling is a professor, Department of Economics, Iowa State University and Head, Resource and Environmental Policy Division, Center for Agricultural and Rural Development, Kathleen Segerson is the Philip E. Austin Professor of Economics Department of Economics University of Connecticut and Jason Shogren is the Stroock Professor of Natural Resource Conservation and Management, University of Wyoming. Shogren thanks the Norwegian University of Life Sciences for their support. Discussions with Joseph Herriges and Spencer Banzhaf were much appreciated.

Amer. J. Agr. Econ. 92(2): 487–505; doi: 10.1093/ajae/aaq012
Received December 2009; accepted January 2010

In response, in the 1950s and 1960s, agricultural economics departments began hiring faculty and training students interested in the economics of nonmarket allocation, particularly focused on environmental and resource management. At the same time, a number of general economists, working at places like Resources for the Future, were also developing research programs on natural resource and environmental issues. In the late 1970s, agricultural and general economists worked together to form the first scholarly association for this new field, the Association of Environmental and Resource Economists (AERE). By the late 1980s, the field was well established, and most agricultural economics departments had at least one faculty member working within the area of environmental or natural resource economics. As the discussion below will show, research in environmental economics really blossomed starting in the 1990s.

Today, few would challenge the idea that agricultural economists are interested in issues related to the environment, and their work has shaped both the public policy debate and the academic literature. Academic contributions have been influential within the policy arena as agricultural economists have offered advice based on the most current tools of the economist's trade. The evidence of the coevolution and cross-fertilization of environmental and agricultural economics is apparent—agricultural economists have played a key role in the development of the field of environmental economics, and work in environmental economics has been a key component of the field of agricultural economics. One measure of how agricultural economists have affected the intellectual development of environmental economists is the AERE Fellows award. By our definition, thirteen of twenty-one AERE Fellows (as of 2008) were agricultural economists,[1] and 8 of 21 papers receiving the AERE "Publication of Enduring Quality" award have been authored or coauthored by agricultural economists. One measure of how environmental economists have affected agricultural economics is in the citations for papers published in the *American Journal of Agricultural Economics* (AJAE, which began publication under that name in 1968) and its predecessor, the *Journal of Farm Economics* (JFE). Of the top 100 papers cited published in the *AJAE*, over one-third (37 of 100) can be categorized as papers dealing with environmental or resource economics. Of the top 10, 7 address environmental issues (5 focus on nonmarket valuation).[2] Clearly, the intersection between the two fields is large.

Herein we highlight some key contributions that agricultural economists have made to environmental economics. As with any brief review, we cannot address the full suite of intellectual contributions by agricultural economists to the discipline of environmental economics. Rather, we focus on three broad areas within environmental economics where the contributions of agricultural economists have been particularly significant and that provide important segues to future growth areas: design of incentives to control environmental externalities, valuing of environmental goods and services, and joint determination (the links, interactions, and feedbacks between economic and environmental systems). With regard to the third area, we note that many topics in this area fall comfortably within the sphere of natural resource economics and are well represented in the paper in this issue by Lichtenberg et al. In fact, many graduate courses in environmental economics would include only the first two topics for in-depth study. However, some examples of joint determination, notably climate change and biodiversity concerns, fit well under the rubric of environmental economics and are likely to be increasingly important in the coming decades. Thus, we include a short section highlighting contributions in this area.

A final caveat: Given that this is a relatively new field, our essay concentrates on work over the last four decades (consider this the "Seussian" era). We point the interested reader to the paper by Castle et al. (1981) for an excellent early review, to Cropper and Oates (1992) for a survey of the field as it stood two decades ago, and to Crocker (1999) for a short history. The reader should also consult a set of papers by Banzhaf (2006, 2009, 2010) for more historical details in specific topics.

[1] One challenge is to define who qualifies as an "agricultural economist." We take a liberal view, assuming that anyone with at least one degree in agricultural economics or employment in an agricultural economics department will not mind being categorized as such.

[2] In contrast, of the top 100 cited papers in the *AJAE*'s predecessor, the *Journal of Farm Economics* (*JFE*), only 5 fit the category of environmental or resource economics (mainly resources) and none appear in the top 40.

Designing Policies to Control Environmental Externalities

A long-standing focus of environmental economics has been the design of policies to control environmental externalities. Increased awareness and concern about the environmental impacts of human activities, precipitated to a large extent by the publication of Rachel Carson's *Silent Spring* in 1962, led to calls for government action to protect society from the negative impacts of pollution. These in turn led to the creation of the U.S. Environmental Protection Agency (EPA) in 1970, the passage of the Clean Air Act in 1970, and the passage of the Federal Pollution Control Act in 1972 (later amended by the Clean Water Act of 1977). Early efforts to control pollution relied primarily on "command-and-control" regulations. However, prompted by concerns about the high cost of standard regulatory approaches, economists generally advocated the use of more flexible policy instruments, based on market incentives. This spawned a large literature on the design of efficient policies for controlling environmental externalities. From the beginning, agricultural economists have played a prominent role in both theoretical and empirical work on environmental policy design, both in the context of agricultural pollution and beyond. Some of the key contributions include the following.

Contribution #1: Agricultural economists have developed the theory underlying innovative incentive-based policies to control environmental externalities for both point and nonpoint source pollution.

Perhaps the most innovative policy prescription contributed by environmental economists since Pigou's early work on taxation of negative externalities is the use of tradable or transferable (discharge) permits, now commonly referred to as "cap-and-trade." A cap-and-trade system either allocates or auctions off a fixed number of permits or allowances to individual polluters, but then allows the permits to be bought or sold. The fixed number of total permits limits total discharges or emissions of the pollutant, while the trading provides the flexibility to ensure that the reduction in aggregate emissions is achieved at least cost. While the idea of cap-and-trade has been around for decades, the positive experience in the United States with the trading of SO_2 permits under the 1990 Clean Air Act amendments and the recent debate over climate change policy have brought the concept of cap-and-trade into the public limelight. The early development of this innovative approach included the work of agricultural economists, most notably Crocker (1966), who developed the basic theory underlying cap-and-trade. The theory was then extended by other agricultural economists to include, for example, transaction costs (Stavins 1995) and intertemporal transfers of permits through banking (Kling and Rubin 1997). In addition, the advantages and disadvantages of a cap-and-trade approach versus a Pigouvian tax (e.g., a carbon tax in the context of climate change) continue to be debated within scholarly and policy arenas, and agricultural economists continue to contribute to this debate with work on climate change. For example, Karp and his coauthors (e.g., Hoel and Karp 2001) have extended the seminal work by Weitzman (1974) comparing taxes and quantity-based (cap-and-trade) policies with the case of stock pollutants (such as CO_2) that accumulate over time.

Early work on cap-and-trade was motivated by the control of point sources of pollution. However, after reductions in major point sources were achieved, the reduction of nonpoint sources, most notably from agriculture, was seen as more cost-effective than achieving further reductions in point sources. This prompted agricultural economists to explore how cap-and-trade schemes could be created for trading across point and nonpoint sources. A key question was the appropriate trading ratio—see the seminal work by then–USDA Economic Research Service (ERS) economists Malik, Letson, and Crutchfield (1993). Although trading across point and nonpoint sources has the potential to reduce costs beyond what is achievable through point-source-only trading, in practice it can be difficult to accurately measure the reductions in pollution loading that stem from agricultural abatement efforts and hence implement the appropriate trading ratios.

Since early efforts to control pollution focused on point sources, in the proposed policies involving point–nonpoint trading, agricultural sources of pollution were typically brought under the "trade" part of the policy but not under the "cap." However, in the 1990s, it became obvious that agricultural production was a key source of water pollution and that subsequent progress toward meeting national water quality goals would require reductions in nonpoint pollution from the agricultural sector. Thus, as some agricultural economists thought about how to bring agricultural sources of pollution under a cap-and-trade system, others were thinking about extending more traditional tax-based pollution control policies to the agricultural sector. However, agricultural pollution poses unique challenges in this regard—the nonpoint (diffuse) nature of most agricultural runoff and the inability to monitor it directly renders standard Pigovian tax policies infeasible. This led agricultural economists to look for different policy approaches that might be used in this context.

In one of the earliest papers on this issue, Griffin and Bromley (1982) developed a theoretical model of nonpoint source pollution and used the model to evaluate alternative policies based on monitoring farmer activities rather than agricultural runoff. This was followed by the development of the theory underlying ambient-based policies, i.e., tax, subsidy, and fixed penalty policies based on observed ambient water quality rather than source emissions. A fundamental issue was the design of appropriate incentives when ambient water quality is affected by random or unknown physical factors (e.g., weather and diffusion coefficients) or by runoff from multiple farms (raising concerns about free-riding and coordination) or both. Segerson (1988) was among the first to formalize the theory underlying the incentives created by ambient-based policies, with subsequent contributions by other agricultural economists, such as Herriges, Govindasamy, and Shogren (1994) and Horan, Shortle, and Abler (1998).

To date, the ambient-based policy instruments discussed above have not been used in practice. As a result, the theoretical predictions of how farmers would respond to the incentives they create cannot be tested with observational data. However, this work has highlighted the main obstacles that must be addressed for successful implementation of economic incentives to address nonpoint source problems. In addition, agricultural economists have recently begun to examine the factors affecting the efficiency of these policies using methods from experimental economic (see, e.g., Vossler et al. 2006). Their potential to effectively control agricultural pollution in practice is still an open question.

Contribution #2: Recognizing the difficulty of implementing first-best policy approaches, agricultural economists have examined the design and relative efficiency of second-best policies, both theoretically and empirically.

The high information or transaction cost associated with theoretical "first-best" control policies, including some of the ambient-based policies, left some agricultural economists skeptical about their practical potential. As applied economists, agricultural economists put a premium on approaches that work in practice, where transaction costs or information requirements matter. Optimal policies that do not address transaction costs will not necessarily be efficient once those extra costs are considered. In other cases, political reality may rule out some policies that would be first-best as defined by economic efficiency.

Motivated by such concerns, agricultural economists have evaluated, theoretically and empirically, the relative efficiency of alternative "second-best" policies, which may not be fully efficient but could still reduce pollution and involve lower information costs. Examples include input taxes on water or chemical/nutrient inputs, standards/regulations, and land use/retirement policies (e.g., Mapp et al. 1994; Helfand and House 1995; Wu and Segerson 1995; Larson, Helfand, and House 1996; Innes 2000). Collectively, this literature suggests that under some conditions, second-best policies can be effective in controlling agricultural pollution with relatively small welfare losses. However, the fact that such policies are not tied directly to the pollution source (e.g., the runoff or leaching of pesticides or fertilizers) means that they may not be well targeted, leading to higher costs, less pollution abatement, or both. Ultimately, the determination of the "best" policy approach must be made on a case-by-case basis.

Contribution #3: Agricultural economists were among the first economists to study voluntary approaches to environmental protection, both theoretically and empirically.

Over the last two decades, scholars and policymakers have become interested in understanding the use of "voluntary approaches" as a public policy tool (Khanna 2001; Alberini and Segerson 2002). The interest in voluntary approaches (VAs) arose primarily out of the desire to find a less costly alternative to command-and-control regulations for controlling point sources of pollution. However, long before VAs emerged as part of the "third wave" of environmental policy design (after command-and-control and market-based incentives), they were already being used in the agricultural sector to induce farmers to adopt conservation or environmentally friendly production practices, and agricultural economists were studying their effectiveness. For example, a series of papers by agricultural economists empirically examined the factors (such as farmer and land characteristics) that influenced voluntary adoption of soil conservation practices or participation in voluntary conservation programs such as the Wetlands Reserve Program and the Conservation Reserve Program (CRP). The studies by Ervin and Ervin (1982), Parks and Kramer (1995), Cooper and Keim (1996), and Parks and Schorr (1997), among others, showed the role of factors such as education, age, land quality, land tenure, and the magnitude of incentive payments in inducing farmers to adopt conservation practices. This literature was a precursor to subsequent studies of voluntary adoption or participation behavior in other VAs.

A key issue in many VAs is the design of the incentive payments used to induce adoption/participation. Given limited budgets, government agencies need to design payments to ensure that resources are used as effectively as possible. This is challenging, since both the cost and hence the decision to participate, as well as the environmental impact (e.g., the reduction in soil erosion or runoff) that would result from participation, will vary across farms. Using models that incorporate biophysical heterogeneity across farms, agricultural economists have shown the importance of targeting payments to achieve maximum environmental benefits from a given expenditure (e.g., Reichelderfer and Boggess 1988; Babcock et al. 1996, 1997; Wu and Boggess 1999). In designing payments, however, it has also been important to recognize the unintended "slippage" that can occur as farmers respond to direct incentives as well as the market effects of conservation programs (Wu 2000). In addition, when farmer or land characteristics that affect adoption decisions or environmental impacts are difficult to observe, incentive payments should reflect this consideration as well. Agricultural economists have applied principles from mechanism design to characterize the optimal design of incentive payments for land retirement or other conservation programs, given asymmetric information about farm types and the ability of farmers to self-select when making participation decisions (e.g., Smith 1995; Wu and Babcock 1996; Wu and Boggess 1999).

Although VAs have historically always been the primary policy tool used to address agricultural pollution, a more general interest in the use of VAs as a pollution control tool in other sectors emerged in the 1990s. Agricultural economists have contributed to this general literature as well. For example, they were among the first researchers to develop theoretical models of VAs designed to identify the conditions under which voluntary approaches are likely to be effective and efficient, or at least more efficient than more traditional regulatory or tax-based approaches (e.g., Segerson and Miceli 1998). While the theoretical literature first focused on point sources of pollution, it has been extended to consider the use of VAs for nonpoint pollution as well (Wu and Babcock 1999; Segerson and Wu 2006). In parallel to the theoretical work, a series of empirical studies by agricultural economists have examined the factors that influenced participation decisions and the impact that participation had on environmental performance. The early work focused on government programs (Khanna and Damon 1999; Videras and Alberini 2000); later work expanded the scope to consider voluntary adoption or changes in production processes designed to improve environmental performance (e.g., Anton, Deltas, and Khanna 2004). Clearly, a better understanding of what motivates participation and its effectiveness are needed if reliance on voluntary approaches is to play a significant role in controlling pollution externalities, either in agriculture or in other sectors.

Contribution #4: Agricultural economists contributed to the development of theory and empirical evidence regarding the effect of information-based approaches to controlling externalities.

Information can also be a powerful tool for inducing behavioral changes, and information disclosure is increasingly being considered as a public policy tool. In some cases, information-based policies are primarily education oriented, providing polluters with information or understanding that will lead directly to changes in production practices. Agricultural economists have explored how information-based policy tools of this type affect behavior and environmental quality. For example, work by agricultural economists in the 1990s showed how soil testing could help inform farmers about when they are overfertilizing a field and could thus lower both costs and pollution by reducing fertilizer use (Fuglie and Bosch 1995; Wu and Babcock 1998).

In addition to directly improving decisions, information can also affect decisions indirectly through the market. For example, in response to information about the environmental performance of firms or characteristics of their products, consumers can adjust their purchasing behavior, organize boycotts, or engage in political activities designed to pressure firms to improve their environmental image. Information disclosure policies such as the EPA's Toxic Release Inventory (TRI) and eco-labeling certification schemes serve this purpose. In some cases (such as the TRI), the disclosure of information is mandatory, while in other cases (such as eco-labeling), firms voluntarily supply information about their environmental practices or performance. Agricultural economists have made key contributions to the understanding of the effectiveness of such policies in a variety of contexts, including wood products (Sedjo and Swallow 2002), dolphin-safe tuna (Teisl, Roe, and Hicks 2002), and toxic wastes (Khanna, Quimio, and Bojilova 1998). Again, how effective such policies are depends on the ability of market participants to pressure firms into changing behavior once the information about that behavior or its impacts is publicly available.

Contribution #5: Agricultural economists have enhanced our understanding of the importance and role of institutions and institutional design.

Much of the work by agricultural economists focuses on specific policies for pollution control. Such policies are embedded in a broader institutional framework that is often taken for granted. Yet, institutions and the property rights they imply are fundamental in defining the relationships that govern all behavior, including behaviors that affect the environment. Agricultural economists have been influential in studying institutions and their design. In some cases, this work has been within the standard neoclassical paradigm. For example, agricultural economists have used standard neoclassical welfare economics to study the incentives created by alternative rules regarding compensation for regulatory actions that restrict the use of private property, aka "regulatory takings" (Miceli and Segerson 1994; Innes 1997; Innes, Polasky, and Tschirhart 1998). More fundamentally, however, some agricultural economists have challenged the standard paradigm, urging a more foundational examination of its underlying premises and implications, particularly as they relate to property rights and behavior (see, e.g., the discussions in Schmid 1972, 1987; Randall 1975; and Bromley 1991).

Valuing Environmental Goods and Services

Marshall, Dupuit, and Hicks—the earliest economists credited with defining welfare concepts such as consumer surplus and compensating variation—are known to most graduates of Ph.D. microeconomics courses. Agricultural and other applied economists then took up the task of developing the analytics and collecting the data needed to generate empirical estimates of these measures. Today we take these methods as standard, but their development required significant ingenuity.

Contribution #6: Agricultural economists were among the first to see the need to incorporate environmental values into public decision making and to provide methods to do so.

The growth of water resources projects in the early twentieth century, especially in the western United States, provided the funds for analysis and planning for major development projects.[3,4] The work related to these projects made clear to many observers that the methods used to incorporate environmental values into cost-benefit analysis were inadequate. During this time, the Park Service sent a request to "experts" asking for ideas about how to place economic values on national parks. Among the recipients of that request was Harold Hotelling, who replied with a detailed letter outlining the "travel cost" method, which is one type of recreation demand model. This method suggested that the cost of travel be used as a proxy for the price of accessing a site and that the equivalent of a demand function be estimated based on observed visitation patterns.

[3] Spencer Banzhaf (2006, 2009, 2010) has written several excellent papers outlining the earliest work and chapters in this history, which provide fascinating detail and context that take the interested reader far beyond our brief introduction.

[4] By the mid-1950s, there was a call for a more uniform set of practices in cost-benefit analysis, and an interagency subcommittee comprising a number of agricultural economists produced a report that came to be known as the *Green Book*. Another important milestone in benefit-cost analysis was the establishment of the Water Resources Council. One of its tasks was to establish continuing planning guidance for water projects. This ultimately led to the *Principles and Guidelines* of 1972, a document that still provides much of the basis for benefit-cost analysis performed by the U.S. Army Corps of Engineers and others.

The first implementation of Hotelling's suggestion is credited to Trice and Wood (1958), although Marion Clawson (1959) used hypothetical data to illustrate Hotelling's idea. Brown, Singh, and Castle (1964) and Clawson and Knetsch (1966) provided the early conceptual underpinnings for the method, and numerous agricultural economists began to apply the method to demonstrate the viability of the approach (Knetsch 1964; Gum and Martin 1975; Stoevener and Brown 1967). A particularly noteworthy contribution in this early era was a paper by Burt and Brewer (1971), who estimated a system of demand equations for six recreation sites and imposed the symmetry conditions on the own-price effects.

Hedonic pricing models were another revealed preference approach that agricultural economists helped develop. Although Rosen (1974) laid the analytical groundwork for using hedonic price theory to value improvements in public goods, agricultural economists had a long history of contributions prior to Rosen's work. Many early contributions were outside the area of environmental economics and are discussed elsewhere.[5] Early advances in using hedonic models for environmental valuation were made by Anderson and Crocker (1971). Further contributions have provided the underpinnings and refinements for using these methods to estimate values for air and water pollution (Smith and Huang 1995; and Leggett and Bockstael 2000).

A third fundamental innovation in nonmarket valuation methods was the "contingent valuation method," which is a survey of the public that today falls under the heading of "stated preference methods." Ciriacy-Wantrup (1947) provided one of the first documented suggestions of this approach; Davis (1963) was the first to implement the idea. The method was bound to be both popular and controversial—popular because the method goes where no market dares; controversial because economists are skeptical about the accuracy of hypothetical values, particularly in the absence of corroborating market evidence. The method, however, remains the only one that can be used to value goods that do not leave a complete market footprint and for which the appropriate context for the value being elicited can be created.[6]

Even for goods that leave a strong market footprint, the context of that footprint may make the good being valued fundamentally different than the good of interest for policy analysis. For example, workers facing risky jobs receive higher compensation than those working less risky jobs. This appears to be the needed market information to value the increased risk to life from environmental pollutants. However, values derived in the context of an adult male choosing voluntarily to accept increased risk on a job site may be inapplicable to cases where involuntary risk is imposed on children because of fundamental differences in how individuals view these risks—the good that leaves the market footprint (voluntary risk to self-selected adults) is different than that needed in benefit-cost analysis of regulations (involuntary risk to children).

Agricultural economists contributed key papers in the early contingent valuation literature that rooted the approach more firmly in economic theory and brought analytically rigorous methods to address its reliability and validity. Work by Randall, Ives, and Eastman (1974) and Hammack and Brown (1974) have proven to be particularly enduring and laid critical groundwork for continuing development of the method (also see Brookshire, Randall, Stoll 1980; Rowe, d'Arge, and Brookshire 1980 and Mitchell and Carson 1989).

Another popular stated preference approach is the "choice experiment" method, which Adamowicz, Boxall, and Willliams (1998) adapted for use in environmental areas. This approach focuses on the multiple attributes of environmental goods, and under appropriate experimental designs marginal values for environmental amenities can be recovered. A major focus of research has been efficient experimental design (Hanley, Wright, and Adamowicz 1998).

Increasingly, agricultural economists do not view stated and revealed preferences as alternative approaches for eliciting welfare estimates, but rather, now see that both pieces of data may be useful to understand underlying preferences. Adamowicz, Louviere, and Williams (1994) and Huang, Haab, and Whitehead (1997) provided careful models that demonstrate the viability of combining information from both approaches in welfare measures.

[5] For a more complete treatment of hedonic models, see the paper by Irwin et al. in the current issue.

[6] For example, lake water quality improvements at a regionally important bird flyway might affect the usage of the lake, thereby leaving a behavioral footprint which can be inferred using recreation demand models but which may leave no footprint with respect to the habitat value for preservation of bird species.

Contribution #7: Agricultural economists contributed to the theory of welfare measurement, thereby providing a strong theoretical foundation for nonmarket valuation.

Throughout the development of both revealed and stated preference approaches, agricultural economists made fundamental advances in the theory of welfare measurement, both within the purview of price changes and as it relates to quality or quantity changes. Given the applied bent of agricultural economists, the range of contributions to welfare theory is indeed remarkable. For example, Just and Hueth (1979) and Just, Hueth, and Schmitz (1982, 2004)[7] provided the theory underpinning welfare measurement in multiple markets and general equilibrium; Randall and Stoll (1980) derived exact welfare measures for quantity changes; and Foster and Just (1989) provided an approach to address the challenging question of how to value information.

In many cases, environmental policy evaluation requires welfare measures associated with quality rather than price changes. The assumption of "weak complementarity" (due to Maler) is central for identifying the circumstances under which environmental values leave an adequate footprint in observed behavior to recover welfare estimates. Agricultural economists (e.g., LaFrance 1999; Bockstael and Kling 1998; Herriges, Kling, and Phaneuf 2004) have teased out many of the theoretical implications of the weak complementarity assumption (Bockstael and McConnell 1993).

Agricultural economists have also been central in developing the theory underlying welfare measurement under uncertainty. Option value, introduced by Weisbrod, is a concept similar to a risk premium, which agricultural economists such as Bishop (1982) have helped to refine, and valuation of risk reduction has been a major focus of research by agricultural economists (Shogren and Crocker 1991, 1999).

Option value's dynamic cousin, quasi-option value, was introduced by Arrow and Fisher (1974), who recognized that under uncertainty there is value associated with an option to wait and gain information to make a better decision. This work has implications beyond environmental economics, as the real options literature in finance demonstrates. Recent contributions (Zhao and Kling 2009) have generalized both option value and quasi-option value to demonstrate the relationship between the concepts and static welfare measures.

[7] This book contains a complete and accessible treatment of welfare measurement and applications.

Contribution #8: Agricultural economists contributed to the fundamental development of econometric models and methods needed to estimate accurately the value of nonmarket goods.

As the nonmarket valuation literature matured, a range of modeling techniques and econometric methods were developed. For revealed preference methods, major early developments included the use of systems of demand equations (Smith and Desvousges 1985; Cicchetti, Fisher, and Smith 1976) and a recognition of the value of collecting individual household-level data rather than relying on aggregate trip data (McConnell 1975). Numerous new empirical challenges and opportunities arose from these richly detailed data sets. Some were largely econometric, such as censoring and truncation of the data at zero (Smith 1988; Englin and Shonkwiler 1995), the count nature of the data (Creel and Loomis 1990), and issues of functional form (Ziemer, Musser, and Hill 1980). Others were related to more accurate representation of preferences, such as how to best address the opportunity cost of time (McConnell and Strand 1981; Bockstael, Strand, and Hanemann 1987; Larson 1993) or how to accurately represent corner solutions in demand systems (Phaneuf 1999; Phaneuf, Kling, and Herriges 2000).

Following McFadden's pioneering work, Hanemann (1978) developed the random utility maximization (RUM) model for valuing no nonmarket goods. This innovation led to a series of papers that adapted and added to the basic model to incorporate multiple choice occasions (Bockstael, Hanemann, and Kling 1987; Morey, Rowe, and Watson 1993). Refinements related to the number of choice occasions (Parsons and Kealy), nesting structure (Kling and Thomson), correlation patterns (Herriges and Phaneuf 2002) and dynamic behavior (Provencher and Bishop 1997).

Much of the basic toolkit for use of stated preference methods in nonmarket valuation is also attributable to agricultural economists. Hanemann's (1984, 1989) "utility difference" approach is one of two key models for analyzing discrete choice contingent valuation data (i.e., yes or no responses to a willingness to pay question).[8] Hanemann, Loomis, and Kanninen (1991) and Herriges and Shogren (1996) extended the discrete choice model to include multiple bounds on bid values. Several refinements and improvements to stated preference methods are attributed to agricultural economists: improvements to the elicitation format (Bateman et al. 1995; Boyle, et al. 1994; Alberini 1995), bid design (Kanninen 1993), and a range of issues related to error structure and econometric specification (Alberini, Kanninen, and Carson 1997; McConnell 1990; Park, Loomis, and Creel 1991; Haab and McConnell 2002).

Contribution #9: Agricultural economists critically evaluated the validity and reliability of nonmarket valuation methods.

Questions surrounding the validity and reliability of stated preference methods as well as their revealed preference counterparts were central in agricultural economists' research agenda from an early date. In an insightful paper, Bishop and Heberlein (1979) put both of the methods to the test in the now famous moose hunting permit study. They arranged with the Wisconsin Department of Natural Resources to sell moose hunting permits to hunters while simultaneously undertaking a contingent valuation and travel cost study of the willingness to pay for the same good. Their findings were important, but arguably more important were the methods they spurred, including the use of real transactions to provide a basis for assessment, the use of discrete choice data for empirical valuation, and the value of comparative approaches to better understand the strengths and limitations of all approaches.

Following Bishop and Heberlein's work, a number of authors undertook comparative studies of welfare estimates generated by alternative methods (Smith, Desvousges, and Fisher 1986; Boyle and Bishop 1988; Boxall et al. 1996). Others designed research to compare values from stated preference methods with values generated via actual transactions (Bishop, Heberlein, and Kealy 1983; Champ, Bishop and Brown 1997; List 2001). These approaches have been used to assess the accuracy and reliability of stated preference methods, though they have also been proposed as methods to provide independent value estimates (Fox et al. 1998). A noteworthy effort is the book by Cummings, Brookshire, and Schulze (1986), which provided an assessment of the state of the art of contingent valuation by the leading scholars at the time. A further impetus for validity and reliability research was the Exxon Valdez oil spill in 1989, which elevated the visibility of nonmarket valuation methods to the general economics profession and broad policy arena (see Hanemann 1994).

By the time the "blue ribbon panel" on contingent valuation was formed to assess the method's usefulness in legal proceedings (NOAA 1993),[9] agricultural economists had already developed a major research inquiry from which the panel could draw to do its work. Once finished, agricultural economists set out to test and evaluate the suggestions of the panel (Carson, et al. 1996; Carson et al. 1998; Loomis 1990; Smith and Osborne 1996). This interest also helped initiate a new set of studies that put contingent valuation and stated preference approaches to the challenging test of comparison with actual market transactions (Neill et al. 1994; Cummings et al. 1997; Cummings and Taylor 1999).[10]

An important spin-off from these validity studies was the observation that empirical findings did not always conform to the predictions of economic theory. Based on this finding, agricultural economists have raised questions that have contributed to the rise of new areas of research in economics, such as behavioral economics. A particularly cogent example relates to the divergence between willingness to pay (WTP) and willingness to accept (WTA) measures of value. The significant divergence between WTP and WTA was initially observed and reported in stated preference work but became a broadly accepted behavioral "anomaly" when it was also demonstrated in laboratory experiments and in the field (Knetsch and Sinden 1984; Coursey, Hovis, and Schulze 1987; Kahneman, Knetsch, and Thaler 1990; Shogren et al. 1994). Horowitz and McConnell (2002) provide an excellent summary and breakdown of many of the studies.

[8] Hanemann's paper is the most-cited article in *AJAE* history, with nearly 500 citations as of the fall of 2009. The other major approach to analyzing contingent valuation data is due to Cameron (1988).

[9] The panel came out of requirements in the Oil Pollution Control Act, passed in response to the Valdez spill, to assess the contingent valuation method.

[10] Interestingly, revealed preference methods have not been subjected to the degree of scrutiny that stated preference methods have, despite the fact that the work by Bishop and Heberlein included both revealed and stated preference methods.

More generally, early work in nonmarket valuation precipitated interest in the variety of biases now prevalently studied in behavioral economics, including information bias, interviewer bias, and status quo bias, among many others (Cummings, Brookshire, and Shultze 1983).

Joint Determination

Joint determination reflects the idea that economic activities and impacts do not occur in a vacuum. Economic decisions affect the natural world around us; the natural world affects our economic decisions. Environmental economists emerging from the agricultural and natural resource tradition have long recognized that neither mankind nor nature is autonomous (e.g., Crocker and Tschirhart 1992). Understanding the links, interactions, and feedback between economic and natural systems has been a long-run goal. The challenge has been how best to address the reality of joint determination across science and policy, given disciplinary boundaries that embrace tractable models and subject specificity within a complex world.

Joint determination has led economists to reach out to other disciplines—both to learn more from them about new cause-and-effect relationships and to demonstrate to them how and why economic principles matters more for other sciences than they might think. Capturing the key links and feedback loops between systems and disciplines allows researchers to explore the consequences of natural and human actions and reactions, which create a feedback loop between the systems. The disturbances in one system impact the other system, and these repercussions feed back into the system where the disturbances originated. People affect nature; nature affects people. Removing the artificial separation between disciplines can change perceptions of how each system works and can provide more effective policy recommendations. Even more fundamental, integrating economic principles with the life sciences, or with different social sciences, can alter the core of both.

Over the years, economists of the agricultural/resource tradition have advanced the joint determination idea with tools stressing the links across and feedback between disciplines. Examples include optimal control theory, endogenous risk theory, human capital models, integrated simulation modeling, stochastic dynamic programming, and experimental methods. These tools have been used to advance our understanding of a number of key interrelationships. We highlight their efforts focusing on two areas, climate change and biodiversity.

Contribution #10: Agricultural economists have used integrated models to estimate the benefits and costs of climate change, particularly related to the agricultural sector.

Understanding the benefits and costs of climate change requires understanding biophysical and economic systems and the interactions between them. Agricultural economists have contributed to the construction of both biophysical-economic frameworks and integrated assessment models that combine the key elements of biophysical and economic systems into one integrated system for studying climate change (see Edmonds and Reilly 1983; Adams 1989; Adams et al. 1990; Reilly et al. 1996). These models focus on capturing basic laws of nature and human behavior to depict how increasing greenhouse gases in the atmosphere raises temperatures, which in turn affects returns in the agricultural sector. The models contain enough detail about the drivers of energy use and the interactions between the energy and agricultural sectors to estimate the economic costs of different policy constraints on carbon emissions. While most of the work by agricultural economists has focused on the impacts on agriculture, integrated models have also been used to estimate the impact of climate change on other resource-intensive sectors, such as timber (Sohngen and Mendelsohn 1998).

In addition to using integrated biophysical-economic models to examine the impact of climate change, agricultural economists have used these models to explore how changes in land use affect energy use and potentially climate change, including the potential for carbon sequestration, both in agricultural soils and in forests (see Adams et al. 1993; Antle et al. 2001; Antle et al. 2003; Sohngen and Mendelsohn 2003). However, in some cases agricultural economists have estimated the impacts of climate change or the costs of carbon sequestration simply from economic models of land use, using for example an hedonic or Ricardian approach (e.g., Parks and Hardie 1995; Stavins 1999; Plantinga, Mauldin, and Miller 1999; Schlenker, Hanemann, and Fisher 2005; Lubowski, Plantinga, and Stavins 2006). These analyses reflect the underlying ecological-economic interactions, although these interactions are considered implicitly rather than modeled explicitly.

Contribution #11: Agricultural economists have played a key role in advancing efficiency in biodiversity management.

By working to integrate economics and ecology/biology into a joint determination framework, economists have help define risks and policies for endangered species moving the field well beyond historical pest management questions (Bishop 1978; Innes, Polasky, and Tschirhart 1998; Brown and Shogren 1998). Since development and conservation decisions depend on economic parameters such as relative prices and income, so too do the risks of biodiversity. Environmental risk assessment requires positive input from the parameters in both the ecological and economic systems that provide the means of choice. Species are more likely to be endangered the greater the conflict with development activities; species are less threatened the greater the conservation efforts. Designing incentives to protect species on private land (Smith and Shogren 2002) and the optimal design of publicly funded reserve systems are a natural outcome of this tradeoff. Of final note, agricultural economists in this area of research have been particularly effective at communicating the role of economic thinking and modeling to scientists in other fields and to policymakers (Ando et al. 1998; Polasky et al. 2005).

Final Thoughts

Our brief review has stressed the rich breadth of contributions that agricultural economists have made to the intellectual reservoir of environmental economics and the broad intersection between the two fields. We summarize here the nature of those contributions and what we have learned from them, with an eye toward looking ahead to potential areas for future contribution.

First, a critical part of efficiently controlling environmental externalities is the design of flexible control mechanisms and incentives in a risky world. A large body of research confirms that individuals respond to incentives and that incentives can be designed to induce private parties to consider environmental impacts in their private decisions. Incentives can be generated by creating markets (and therefore prices) for environmental goods and services, through, for example, taxes or cap-and-trade systems. These policies offer opportunities for cost-effective reductions in pollution under which least-cost abatement options are exploited. However, the diffuse nature of agricultural nonpoint source pollution makes application of traditional incentive-based approaches difficult, if not infeasible, in this context. For example, trading across point and nonpoint sources of pollution faces significant challenges in terms of identifying and implementing appropriate trading ratios. Alternatively, ambient-based policies or second-best approaches can be used, but neither offers a panacea. Second-best policies are by definition imperfect, and while in theory ambient-based policies can be designed to create efficient incentives, the potential for these approaches to efficiently control nonpoint source pollution has not yet been demonstrated empirically. Finally, voluntary approaches can be used, although it is important to understand the factors that are likely to lead to participation or adoption of voluntary approaches and to create incentives for participation/adoption. Information can also create incentives for changes in behavior, either by making farmers aware of practices (such as overfertilization) that both raise costs and increase pollution or by providing consumers (or more generally market participants) with information that can be used to pressure polluters to change their behavior. However, the strength of the incentives created by these types of policies is still an open question.

Second, it is clear from the past several decades of research that we now have methods and tools that can be used to value both human and ecosystem health, albeit imperfectly. Conceptually, the theoretical underpinnings for welfare measurement have been defined—theory provides an understanding of what we want to measure. Empirically, we have identified and refined methods to measure nonmarket values. However, questions remain about the accuracy and applicability of both revealed and stated preference approaches, which will likely continue to make this area of research one of continuing interest to agricultural and environmental economists. A major challenge is to understand how the insight from work in behavioral economics can contribute to, or require the reinterpretation of, welfare measurement. Further refinements in methods will continue to be a major part of agricultural economists' research portfolio, with an emphasis on combining information sources from both revealed and stated preferences. Finding better ways to inform decision makers about tradeoffs between equity and efficiency is also an area ripe for improvement.

Third, understanding and addressing the most pressing environmental challenges of today and the future requires a recognition of the inextricable link between humans and nature. This calls for research that integrates economics and other disciplines like ecology, biology, psychology, toxicology, hydrology, and engineering and that draws on tools capable of capturing key interrelationships over space and time. In addition, variables previously viewed as exogenous must now be recognized as endogenously determined by the integrated system. Addressing the joint determination issue clearly complicates analyses, but the successes in integrated modeling over the past two decades suggest that doing so is both feasible and, in many cases, necessary for understanding and addressing critical problems such as climate change and biodiversity losses.

The history of contributions of agricultural economists to the study of environmental problems points to the key role that they have played not only in defining the field but in shaping environmental policy debates over the last several decades. While we will be around to witness only part of it, we are confident that the two fields will continue to coevolve over the next 100 years, with substantial cross-fertilization between general economists and agricultural economists who work on environmental economics.

References

Adamowicz, W., P. Boxall, M. Williams. 1998. Stated Preference Approaches for Measuring Passive Use Values: Choice Experiments and Contingent Valuation. *American Journal of Agricultural Economics* 80: 64–75.

Adamowicz, W., J. Louviere, and M. Williams. 1994. Combining Revealed and Stated Preference Methods for Valuing Environmental Amenities. *Journal of Environmental Economics and Management* 26: 271–292.

Adams, R. 1989. Global Climate Change and Agriculture: An Economic Perspective. *American Journal of Agricultural Economics* 71: 1272–1279.

Adams, R., C. Rosenzweig, R. Peart, J. Ritchie, B. McCarl, J. Glyer, R. Curry, J. Jones, K. Boote, and L. Allen. 1990. Global Climate Change and US Agriculture. *Nature* 345: 219–224.

Adams, R., D. Adams, J. Callaway, C. Chang, and B. McCarl. 1993. Sequestering Carbon on Agricultural Land: Social Cost and Impacts on Timber Markets. *Contemporary Policy Issues* 11: 76–87.

Alberini, A. 1995. Efficiency vs. Bias of Willingness-to-Pay Estimates: Bivariate and Interval-Data Models. *Journal of Environmental Economics and Management* 29: 169–180.

Alberini, A., B. Kanninen, and R. Carson. 1997. Modeling Response Incentive Effects in Dichotomous Choice Contingent Valuation Data. *Land Economics* 73: 309–324.

Alberini, A., and K. Segerson. 2002. Assessing Voluntary Programs to Improve Environmental Quality. *Environmental and Resource Economics* 22: 157–184.

Anderson, R. J., and T. D. Crocker. 1971. Air Pollution and Residential Property Values. *Urban Studies* 8: 171–180.

Ando, A., J. Camm, S. Polasky, and A. Solow. 1998. Species Distributions, Land Values, and Efficient Conservation. *Science* 279: 2126–2128.

Antle, J., S. M. Capalbo, S. Mooney, E. T. Elliott, and K. H. Paustian. 2001. Economic Analysis of Agricultural Soil Carbon Sequestration: An Integrated Assessment Approach. *Journal of Agricultural and Resource Economics* 26: 344–367.

———. 2003. Spatial Heterogeneity, Contract Design, and the Efficiency of Carbon Sequestration Policies for Agriculture. *Journal of Environmental Economics and Management* 46: 231–250.

Anton, W. R., G. Deltas, and M. Khanna. 2004. The Incentives for Environmental Self-Regulation and Implications for Environmental Performance. *Journal of Environmental Economics and Management* 48: 632–654.

Arrow, K., and A. Fisher. 1974. Environmental Preservation, Uncertainty, and Irreversability. *Quarterly Journal of Economics* 88: 312–319.

Babcock, B. A., P. G. Lakshminarayan, J. J. Wu, and D. Zilberman. 1996. The Economics of a Public Fund for Environmental Amenities: A Study of CRP Contracts. *American Journal of Agricultural Economics* 78: 961–971.

Babcock, B. A., P. G. Lakshminarayan, J. J. Wu, and D. Zilberman. 1997. Targeting Tools for the Purchase of Environmental Amenities. *Land Economics* 73: 325–339.

Banzhaf, H. S. 2006. The Other Economics Department: Demand and Value Theory in Early Agricultural Economics. *History of Political Economy* 38: 9–31.

———. 2009. Objective or Multi-Objective? Two Historically Competing Visions for Benefit-Costs Analysis. *Land Economics* 85: 3–23.

Bateman, I. J., I. H. Langford, R. K. Turner, K. G. Willis, and G. D. Garrod. 1995. Elicitation and Truncation Effects in Contingent Valuation Studies. *Ecological Economics* 12 : 161–179.

Bishop, R. C. 1978. Endangered Species and Uncertainty: Economics of a Safe Minimum Standard. *American Journal of Agricultural Economics* 60: 10–18.

———. 1982. Option Value – An Exposition and Extension. *Land Economics* 58: 1–15.

Bishop, R., and T. Heberlein. 1979. Measuring Values of Extra-Market Goods: Are Indirect Measures Biased? *American Journal of Agricultural Economics* 61: 926–930.

Bishop, R., T. A. Heberlein, and M. J. Kealy. 1983. Contingent valuation of environmental assets: Comparisons with a simulated market. *Nat. Resour. J.* 23: 619–633.

Bockstael, N. and C. Kling. 1988. Valuing Environmental Quality Changes when Quality is a Weak Complement to a Set of Goods. *American Journal of Agricultural Economics* 70: 654–662.

Bockstael, N. E., W. M. Hanemann, and C. L. Kling. 1987. Measuring Recreational Demand in a Multiple Site Framework. *Water Resources Research* 23: 951–960.

Bockstael, N., and K. McConnell. 1993. Public Goods as Characteristics of Non-Market Commodities. *Economic Journal* 103: 1244–1257.

Bockstael, N. E., I. E. Strand, and W. M. Hanemann. 1987. Time and the Recreational Demand Model. *American Journal of Agricultural Economics* 69: 293–302.

Boxall, P. C., W. L. Adamowicz, J. Swait, M. Williams, and J. Louviere. 1996. A Comparison of Stated Preference Methods for Environmental Valuation. *Ecological Economics* 18 3: 243–253.

Boyle, K. J., and R. C. Bishop. 1988. Welfare Measurements Using Contingent Valuation: A Comparison of Techniques. *American Journal of Agricultural Economics* 70: 20–28.

Boyle, K. J., W. H. Desvousges, F. R. Johnson, R. W. Dunford, and S. P. Hudson. 1994. An Investigation of Part-While Biases in Contingent Valuation Studies. *Journal of Environmental Economics and Management* 27 (1): 64–83.

Bromley, D. W. 1991. *Environment and Economy: Property Rights and Public Policy.* New York: Basil Blackwell.

Brookshire, D. S., A. Randall, and J. R. Stoll. 1980. Valuing Increments and Decrements in Natural-Resource Flows. *American Journal of Agricultural Economics* 62: 478–488.

Brown, G. M., and J. F. Shogren. 1998. Economics of the Endangered Species Act. *Journal of Economic Perspectives* 12: 3–20.

Brown, W. G., A. Singh, and E. N. Castle. 1964. An Economic Evaluation of the Oregon Salmon and Steelhead Sport Fishery, Technical Bulletin No. 78, Agricultural Experiment Station, Oregon State University, Corvallis, September.

Burt, O., and D. Brewer. 1971. Estimation of Net Social Benefits from Outdoor Recreation. *Econometrica* 39: 813–827.

Cameron, T. A. 1988. A New Paradigm for Valuing Non-Market Goods Using Referendum Data: Maximum Likelihood Estimation by Censored Logistic-Regression. *Journal of Environmental Economics and Management* 15: 355–379.

Castle, E., M. Kelso, J. Stevens, and H. Stoevener. 1981. Natural Resource Economics, 1946–1975. In Lee Martin, ed. *A Survey of Agricultural Economics Literature, Volume 3*, Minneapolis: University of Minnesota Press.

Carson, R. T., N. E. Flores, K. M. Martin, and J. L. Wright. 1996. Contingent Valuation and Revealed Preference Methodologies: Comparing the Estimates for Quasi-Public Goods. *Land Economics* 72 1: 80–99.

Carson, R., W. Hanemann, R. Kopp, J. Krosnick, R. Mitchell, S. Presser, P. Ruud, and V. Smith. 1998. Referendum Design and Contingent Valuation: The NOAA Panel's

No-Vote Recommendation. *Review of Economics and Statistics* 80: 335–338.

Champ, P. A., R. C. Bishop, and T. C. Brown. 1997. Using Donation Mechanisms to Value Nonuse Benefits from Public Goods. *Journal of Environmental Economics and Management* 33: 151–162.

Cicchetti, C., A. Fisher, and V. Smith. 1976. An Econometric Evaluation of a Generalized Consumer Surplus Measure: The Mineral King Controversy. *Econometrica* 44: 1259–1276.

Ciriacy-Wantrup, S. 1947. Capital Returns from Soil-Conservation Practices. *Journal of Farm Economics* 29: 1181–85.

Clawson, Marion. 1959. Methods of Measuring the Demand for and Value of Outdoor Recreation, RFF Reprint 10, pp. 1–36. Washington DC: Resources for the Future.

Clawson, M., and J. Knetsch. 1966. *Economics of Outdoor Recreation.* Baltimore: Johns Hopkins Press/Resources for the Future.

Cooper, J. C., and R. W. Keim. 1996. Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices. *American Journal of Agricultural Economics* 78: 54–64.

Coursey, D., J. L. Hovis, and W. D. Schulze. 1987. The Disparity between Willingness to Accept and Willingness to Pay Measures of Value. *Quarterly Journal of Economics* 102: 679–690.

Creel, M., and J. Loomis. 1990. Theoretical and Empirical Advantages of Truncated Count Data Estimators for Analysis of Deer Hunting in California. *American Journal of Agricultural Economics* 72: 434–441.

Crocker, T. D. 1966. The Structuring of Atmospheric Pollution Control Systems. In H. Wolozin, ed. *The Economics of Air Pollution*, pp. 61–86. New York: Norton.

———. 1999. A Short History of Environmental and Resource Economics. In Jeroen C. van den Bergh, ed. *Handbook of Environmental and Resource Economics,* pp. 32–45. Cheltenham, UK: Edward Elgar.

Crocker T., and J. Tschirhart. 1992. Ecosystems, Externalities, and Economics. *Environmental and Resource Economics* 2: 551–567.

Cropper, M., and W. Oates. 1992. A Survey of Environmental Economics. *Journal of Economic Literature* 30: 675–740.

Cummings, R., D. Brookshire, and W. Schulze. 1986. *Valuing Environmental Goods: An Assessment of the Contingent Valuation Method*, Totowa, NJ: Rowman and Allanheld.

Cummings, R. and L. Taylor. 1999. Unbiased Value Estimates for Environmental Goods: A Cheap Talk Design for the Contingent Valuation Method. *American Economic Review* 89: 649–665.

Cummings, R., S. Elliott, G. Harrison, and J. Murphy. 1997. Are Hypothetical Referenda Incentive Compatible? *Journal of Political Economy* 105: 609–621.

Cummings, R. G., D. S. Brookshire, and W. D. Schulze. 1983. *An Assessment of the Contingent Valuation Method*, with contributions by R. Bishop, D. Coursey, A. M. Freeman, T. Heberlein, A. Randall, and V. K. Smith. Totowa, NJ: Rowman & Allanheld.

Davis, R. K. 1963. Recreation Planning as an Economic Problem. *Natural Resources Journal* 3: 239–49.

Edmonds J. A., and J. M. Reilly. 1983. A Long-Term Global Energy-Economic Model of Carbon Dioxide release from Fossil Fuel Use. *Energy Economics* 4: 74–88.

Englin, J., and J. Shonkwiler. 1995. Estimating Social Welfare Using Count Data Models: An Application to Long-Run Recreation Demand under Conditions of Endogenous Stratification and Truncation. *Review of Economics and Statistics* 77: 104–112.

Ervin, C. A., and D. E. Ervin. 1982. Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence, and Policy Implications. *Land Economics* 58: 277–292.

Foster, W. E., and R. E. Just. 1989. Measuring the Welfare Effects of Product Contamination with Consumer Uncertainty. *Journal of Environmental Economics and Management* 17: 266-233.

Fox, J. A., J. F. Shogren, D. J. Hayes, and Y. Shin. 1998. CVM-X: Calibrating Contingent Values with Experimental Auction Markets. *American Journal of Agricultural Economics* 80: 455–465.

Fuglie, K. O., and D. J. Bosch. 1995. Economic and Environmental Implications of Soil Nitrogen Testing: A Switching Regression Analysis. *American Journal of Agricultural Economics* 77: 891–900.

Griffin, R. C., and D. W. Bromley. 1982. Agricultural Runoff as a Nonpoint Externality:

A Theoretical Development. *American Journal of Agricultural Economics* 64: 547–552.

Gum, R. L., and W. E. Martin. 1975. Problems and Solutions in Estimating the Demand for and Value of Rural Outdoor Recreation. *American Journal of Agricultural Economics* 57: 558–566.

Haab, T., and K. McConnell. 2002. The Econometrics of Nonmarket Valuation. Edward Elgar, New Horizons in Environmental Economics series.

Hammack, J., and Brown, G. M. 1974. *Waterfowl and Wetlands: Toward Bio-Economic Analysis.* Baltimore: Resources for the Future/Johns Hopkins University Press.

Hanemann, M. 1984. Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses. *American Journal of Agricultural Economics* 66: 332–341.

———. 1989. Welfare Evaluations in Contingent Valuation Experiments with Discrete Response Data: Reply. *American Journal of Agricultural Economics* 71: 1057–1061.

Hanemann, M., J. Loomis, and B. Kanninen. 1991. Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation. *American Journal of Agricultural Economics* 73: 1255–1263.

Hanemann, W. M. 1978. A Methodological and Empirical Study of the Recreation Benefits from Water Quality Improvement. Ph.D. dissertation, Department of Economics, Harvard University.

———. 1994. Valuing the Environment through Contingent Valuation. *Journal of Economic Perspectives* 8: 19–43.

Hanley, N., R. E. Wright, and V. Adamowicz. 1998. Using Choice Experiments to Value the Environment—Design Issues, Current Experience, and Future Prospects. *Environmental and Resource Economics* 11: 314–428.

Helfand, G. E., and B. W. House. 1995. Regulating Nonpoint-Source Pollution under Heterogeneous Conditions. *American Journal of Agricultural Economics* 77: 1024–1032.

Herriges, J. A., R. Govindasamy, and J. F. Shogren. 1994. Budget-Balancing Incentive Mechanisms. *Journal of Environmental Economics and Management* 27: 275–285.

Herriges, J. A., and J. F. Shogren. 1996. Starting Point Bias in Dichotomous Choice Valuation with Follow-up Questioning. *Journal of Environmental Economics and Management* 30: 112–131.

Herriges, J. A., and D. Phaneuf. 2002. Inducing Patterns of Correlation and Substitution in Repeated Logit Models of Recreation Demand. *American Journal of Agricultural Economics* 84: 1076–1090.

Hoel, M., and L. Karp. 2001. Taxes and Quotas for a Stock Pollutant with Multiplicative Uncertainty. *Journal of Public Economics* 82: 91–114.

Horan, R. D., J. S. Shortle, and D. G. Abler. 1998. Ambient Taxes When Polluters Have Multiple Choices. *Journal of Environmental Economics and Management* 36: 186–199.

Horowitz, J. K., and K. E. McConnell. 2002. A Review of WTA/WTP Studies. *Journal of Environmental Economics and Management* 44: 426–447.

Huang, J.-C., T. Haab, and J. Whitehead. 1997. Willingness to Pay for Quality Improvements: Should Revealed and Stated Preference Data be Combined? *Journal of Environmental Economics and Management* 34: 240–255.

Innes, R. 1997. Takings, Compensation, and Equal Treatment for Owners of Developed and Undeveloped Property. *Journal of Law and Economics* 40: 403–432.

———. 2000. The Economics of Livestock Waste and its Regulation. *American Journal of Agricultural Economics* 82: 97–117.

Innes, R., S. Polasky, and J. Tschirhart. 1998. Takings, Compensation and Endangered Species Protection on Private Lands. *Journal of Economic Perspectives* 12: 35–52.

Just, R., and D. Hueth. 1979. Welfare Measures in a Multimarket Framework. *American Economic Review* 69: 77–98.

Just, R. E., D. L. Hueth, and A. Schmitz, 1982. Applied Welfare Economics and Public Policy, Englewood Cliffs, NJ: Prentice Hall.

Kahneman, D., J. L. Knetsch, and R. H. Thaler. 1990. Experimental tests of the endowment effect and the Coase theorem. *Journal of Political Economy* 98: 1325–1348.

Kanninen, B. 1993. Optimal Experimental Design for Double-Bounded Dichotomous Choice Contingent Valuation. *Land Economics* 69: 138–143.

Khanna, M. 2001. Non-mandatory Approaches to Environmental Protection. *Journal of Economic Surveys* 15: 291–324.

Khanna, M., and L. A. Damon. 1999. EPA's Voluntary 33/50 Program: Impact on Toxic Releases and Economic Performance of Firms. *Journal of Environmental Economics and Management* 37: 1–25.

Khanna, M., W. R. Quimio, and D. Bojilova. 1998. Toxics Release Information: A Policy Tool for Environmental Protection. *Journal of Environmental Economics and Management* 36: 243–266.

Kling, C., and J. Rubin. 1997. Bankable Permits for the Control of Environmental Pollution. *Journal of Public Economics* 64: 101–115.

Kling, C. L., and C. Thomson. 1996. The Implications of Model Specification for Welfare Estimation in Nested Logit Models. *American Journal of Agricultural Economics* 78: 103–114.

Knetsch, J. L. 1964. Economics of Including Recreation as a Purpose of Eastern Water Projects. *Journal of Farm Economics* 46:1148–1157.

Knetsch, J. L., and J. A. Sinden. 1984. Willingness to Pay and Compensation Demanded: Experimental Evidence of an Unexpected Disparity in Measures of Value. *Quarterly Journal of Economics* 99: 507–521.

LaFrance, Jeffrey. 1994. *Weak Complementarity and Other Normative Speculations*. W-133 proceedings, University of Kentucky.

Larson, D. M. 1993. Separability and the Shadow Value of Leisure–time. *American Journal of Agricultural Economics* 75: 572–577.

Larson, D. M., G. E. Helfand, and B. W. House. 1996. Second-Best Tax Policies to Reduce Nonpoint Source Pollution. *American Journal of Agricultural Economics* 78: 1108–1117.

Leggett, C. G., and N. E. Bockstael. 2000. Evidence of the Effects of Water Quality on Residential Land Prices. *Journal of Environmental Economics and Management* 39: 121–144.

List, J. 2001. Do Explicit Warnings Eliminate the Hypothetical Bias in Elicitation Procedures? Evidence from Field Auctions for Sports Cards. *American Economic Review* 91: 324–340.

Loomis, J. B. 1990. Comparative Reliability of the Dichotomous Choice and Open-Ended Contingent Valuation Techniques. *Journal of Environmental Economics and Management* 18: 78–85.

Lubowski, R. N., A. J. Plantinga, and R. N. Stavins. 2006. Land Use Change and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function. *Journal of Environmental Economics and Management* 51: 135–152.

Malik, A. S., D. Letson, and S. R. Crutchfield. 1993. Point/Nonpoint Source Trading of Pollution Abatement: Choosing the Right Trading Ratio. *American Journal of Agricultural Economics* 75: 959–967.

Mapp, H. P., D. J. Bernardo, G. J. Sabbagh, S. Geleta, and K. B. Watkins. 1994. Economic and Environmental Impacts of Limiting Nitrogen Use to Protect Water Quality—A Stochastic Regional Analysis. *American Journal of Agricultural Economics* 76: 889–903.

McConnell, K. E. 1990. Models for Referendum Data: The Structure of Discrete Choice Models for Contingent Valuation. *Journal of Environmental Economics and Management* 18: 19–34.

———. 1975. Some Problems in Estimating Demand for Outdoor Recreation. *American Journal of Agricultural Economics* 57: 330–334.

McConnell, K. E., and I. E. Strand. 1981. Measuring the Cost of Time in Recreation Demand Analysis: An Application to Sport Fishing. *American Journal of Agricultural Economics* 63: 153–156.

Miceli, T. J., and K. Segerson. 1994. Regulatory Takings—When Should Compensation be Paid? *Journal of Legal Studies* 23: 749–776.

Mitchell, Robert Cameron and Carson, Richard T. 1989. *Using surveys to value public goods: The contingent valuation method*. Washington, D.C.: Resources for the Future.

Morey, E., R. Rowe, and M. Watson. 1993. A Repeated Nested-Logit Model of Atlantic Salmon Fishing. *American Journal of Agricultural Economics* 75: 578–592.

Neill, H., R. Cummings, P. Garderton, G. Harrison, and T. McGuckin. 1994. Hypothetical Surveys and Real Economic Commitments. *Land Economics* 70: 145–154.

National Oceanic and Atmospheric Administration. 1993. Panel on Contingent Valuation Arrow, Solow, Leamer, Portney, and Radner Natural Resource Damage Assessments under the Oil Pollution Act of 1990. *Federal Register* 58: January 15.

Park, T., Loomis, J. B., and M. Creel. 1991 Confidence Intervals for Evaluation Benefit Estimates from Dichotomous Choice Contingent Valuation Studies. *Land Economics 67*: 64–73.

Parks, P. J., and I. W. Hardie. 1995. Least Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forests. *Land Economics* 71: 122–136.

Parks, P. J., and R. A. Kramer. 1995. A Policy Simulation of the Wetlands Reserve Program. *Journal of Environmental Economics and Management* 28: 223–240.

Parks, P. J., and J. P. Schorr. 1997. Sustaining Open Space Benefits in the Northeast: An Evaluation of the Conservation Reserve Program. *Journal of Environmental Economics and Management* 32: 85–94.

Parsons, G., and M. J. Kealy. 1992. Randomly Drawn Opportunity Sets in a Random Utility Model of Lake Recreation. *Land Economics* 68: 93–106.

Phaneuf, D. J. 1999. A Dual Approach to Modeling Corner Solutions in Recreation Demand. *Journal of Environmental Economics and Management* 37: 85–105.

Phaneuf, D. J., C. Kling, and J. Herriges. 2000. Estimation and Welfare Calculations in a Generalized Corner Solution Model with an Application to Recreation Demand. *Review of Econometrics and Statistics* 82: 83–92.

Phaneuf, D., J. Herriges, and C. Kling. 2004. What's the Use: Welfare Estimates from Revealed Preference Models in the Absence of Weak Complementarity. *Journal of Environmental Economics and Management* 47: 53–68

Plantinga, A. J., T. Mauldin, and D. J. Miller. 1999. An Econometric Analysis of the Costs of Sequestering Carbon in Forests. *American Journal of Agricultural Economics* 81: 812–824.

Polasky, S., E. Nelson, E. Lonsdorf, P. Fackler, and A. Starfield. 2005. Conserving Species in a Working Landscape: Land Use with Biological and Economic Objectives. *Ecological Applications* 15:1387–1401.

Provencher, W., and R. C. Bishop. 1997. An Estimable Dynamic Model of Recreation Behavior with an Application to Great Lakes Angling. *Journal of Environmental Economics and Management* 33: 53–68.

Randall, A. 1975. Property Rights and Social Microeconomics. *Natural Resources Journal* 15: 729–748.

Randall, A., I. Ives, and C. Eastman. 1974. Bidding Games for Valuation of Aesthetic Environmental Improvements. *Journal of Environmental Economics and Management* 1: 132–149.

Randall, A., and J. Stoll. 1980. Consumer's Surplus in Commodity Space. *American Economic Review* 70: 235–256.

Reichelderfer, K., and W. G. Boggess. 1988. Government Decision Making and Program Performance: The Case of the Conservation Reserve Program. *American Journal of Agricultural Economics* 70: 1–11.

Reilly, J., Bzethgen, W., Chege, F. E., van de Greijin, S. C., Ferda, L., Iglesias, A., Kenny, C., Patterson, D., Rogasik, J., Rotter, R., Rosenzweig, C., Sombroek, W. and Westbrook, J. 1996. Agriculture in a Changing Climate: Impacts and Adaptations. In Watson et al., ed. *Climate Change, 1995: Impact, Adaptation and Mitigation of Climate Change-Scientific-Technical Analyses*, New York: Cambridge University Press.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82: 34–55.

Rowe, R. D., R. C. D'Arge, and D. S. Brookshire. 1980. Experiment on the Economic Value of Visibility. *Journal of Environmental Economics and Management* 7: 1–19.

Schlenker, W., W. M. Hanemann, and A. C. Fisher. 2005. Will US Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach. *American Economic Review* 95: 395–406.

Schmid, A. A. 1972. Analytical Institutional Economics: Challenging Problems in the Economics of Resources for a New Environment. *American Journal of Agricultural Economics* 54: 893–901.

———. 1987. *Property, Power and Public Choice: An Inquiry into Law and Economics*, 2nd ed. New York: Praeger.

Sedjo, R. A., and S. K. Swallow. 2002. Voluntary Eco-labeling and the Price Premium. *Land Economics* 78: 272–284.

Segerson, K. 1988. Uncertainty and Incentives for Nonpoint Pollution Control. *Journal* *of Environmental Economics and Management* 15: 87–98.

Segerson, K., and T. J. Miceli. 1998. Voluntary Environmental Agreements: Good or Bad News for Environmental Protection? *Journal of Environmental Economics and Management* 36: 109–130.

Segerson, K., and J. J.Wu. 2006. Nonpoint Pollution Control: Inducing First-Best Outcomes through the Use of Threats. *Journal of Environmental Economics and Management* 51: 165–184.

Shogren, J., and T. Crocker. 1991. Risk, Self Protection, and Ex Ante Economic Value. *Journal of Environmental Economics and Management* 20: 1–15.

Shogren, J., and T. Crocker. 1999. Risk and Its Consequences. *Journal of Environmental Economics and Management* 37: 44–51.

Shogren, J., S. Shin, D. Hayes, and J. Kliebenstein. 1994. Resolving Differences in Willingness to Pay and Willingness to Accept. *American Economic Review* 84: 255–270.

Smith, R. B. 1995. The Conservation Reserve Program as a Least Cost Land Retirement Mechanism. *American Journal of Agricultural Economics* 77: 93–105.

Smith, R. B., and J. F. Shogren. 2002. Voluntary Incentive Design for Endangered Species Protection. *Journal of Environmental Economics and Management* 43: 169–187.

Smith, V. K. 1988. Selection and Recreation Demand. *American Journal of Agricultural Economics* 70: 29–36.

Smith, V. K., and W. H. DesVousges. 1985. The Generalized Travel Cost Model and Water-Quality Benefits: A Reconsideration. *Southern Economic Journal* 52: 371–381.

Smith, V. K., W. H. DesVousges, and A. Fisher. 1986. A Comparison of Direct and Indirect Methods for Estimating Environmental Benefits. *American Journal of Agricultural Economics* 68: 280–290.

Smith, V. K., and L. L. Osborne. 1996. Do Contingent Valuation Estimates Pass a Scope Test? A Meta-Analysis. *Journal of Environmental Economics and Management* 31: 287–301.

Smith, V., and J. Huang. 1995. Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Models. *Journal of Political Economy* 103: 209–227.

Sohngen, B., and R. Mendelsohn. 1998. Valuing the Impact of Large-Scale Ecological Change in a Market: The Effect of Climate Change on US Timber. *American Economic Review* 88: 686–710.

———. 2003. An Optimal Control Model of Forest Carbon Sequestration. *American Journal of Agricultural Economics* 85: 448–457.

Stavins, R. N. 1995. Transaction Costs and Tradeable Permits. *Journal of Environmental Economics and Management* 29: 133–148.

Stavins, R. N. 1999. The Costs of Carbon Sequestration: A Revealed Preference Approach. *American Economic Review* 89: 994–1009.

Stoevener, H. H., and W. G. Brown. 1967. Analytical Issues in Demand Analysis for Outdoor Recreation. *Journal of Farm Economics* 49:1295–1301.

Teisl, M. F., B. Roe, and R. L. Hicks. 2002. Can Eco-labels Tune a Market? Evidence from Dolphin-Safe Labeling. *Journal of Environmental Economics and Management* 43: 339–359.

Trice, Andrew and Samuel Wood. 1958. Measurement of Recreation Benefits. *Land Economics* 34: 365–67.

Videras, J., and A. Alberini. 2000. The Appeal of Voluntary Environmental Programs: Which Firms Participate and Why? *Contemporary Economic Policy* 18: 449–461.

Vossler, C. A., G. L. Poe, W. D. Schulze, and K. Segerson. 2006. Communication and Incentive Mechanisms Based on Group Performance: An Experimental Study of Nonpoint Pollution Control. *Economic Inquiry* 44: 599–613.

Weitzman, M. L. 1974. Prices vs. Quantities. *Review of Economic Studies* 41: 477–491.

Wu, J. J. 2000. Slippage Effects of the Conservation Reserve Program. *American Journal of Agricultural Economics* 82: 979–992.

Wu, J. J., and B. A. Babcock. 1996. Contract Design for the Purchase of Environmental Goods from Agriculture. *American Journal of Agricultural Economics* 78: 935–945.

———. 1998. The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications. *American Journal of Agricultural Economics* 80: 494–511.

———. 1999. The Relative Efficiency of Voluntary vs. Mandatory Environmental

Regulations. *Journal of Environmental Economics and Management* 38: 158–175.

Wu, J. J., and W. G. Boggess. 1999. The Optimal Allocation of Conservation Funds. *Journal of Environmental Economics and Management* 38: 302–321.

Wu, J. J., and K. Segerson. 1995. The Impact of Policies and Land Characteristics on Potention Groundwater Pollution in Wisconsin. *American Journal of Agricultural Economics* 77: 1033–1047.

Zhao, J., and C. Kling. 2009. Welfare Measures When Agents Can Learn: A Unifying Theory. *Economic Journal* 119: 1560–1585.

Ziemer, R., W. Musser, and R. Hill. 1980. Recreation Demand Equations: Functional Form and Consumer Surplus. *American Journal of Agricultural Economics* 62: 136–141.