The Economic Valuation of Environmental Amenities and Disamenities: Methods and Applications

Robert Mendelsohn and Sheila Olmstead

School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut 06511; email: robert.mendelsohn@yale.edu, sheila.olmstead@yale.edu

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Abstract

There have been significant improvements over the past four decades in our ability to estimate the economic value of environmental amenities and disamenities. The development of many new techniques has broadened what can be measured to include climate change impacts, damages from hazardous waste sites and air pollution emissions, and the value of many ecosystem services. We review the major economic valuation techniques, as well as numerous applications of these valuation methods. However, there remain challenges ahead. The interface between economics and the natural and physical sciences must be strengthened. Additional well-controlled "natural experiments" are always needed. The application of valuation methods outside of the United States remains a monumental task. Reliable measures of nonuse values remain elusive.

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1. INTRODUCTION

Environmental and natural resource economists have developed methods to estimate the benefits of preserving environmental goods and services (and, conversely, the damages when such resources are destroyed or depleted). If the benefits of environmental protection can be measured, they can be compared with costs. Decision makers can then implement environmental policies that maximize the net benefits of such choices to society—what economists refer to as maximizing social welfare. A policy that maximizes social welfare is economically efficient, and most economists consider movements toward efficiency, measured through benefit-cost analysis, a critical criterion in environmental policy design.

The economic benefit provided by an environmental good or service is the sum of what all members of society would be willing to pay for it. For resources traded in markets such as oil, land, timber, and crops, the value of small quantities of market goods can be measured by their observed price. In competitive markets, prices reflect both the marginal cost of producing the good to suppliers and the marginal value to consumers. Prices are readily observed and constantly updated.

In order to value larger changes in market goods, we use the demand and supply function for each good. The demand function is the relationship between the quantity of a good desired by the consumer and its price. The supply function is the relationship between the quantity of a good firms will provide and its price. The total value of the good is the net consumer and producer surplus, the difference between the area underneath the demand function and above supply function up to the amount consumed. It is the difference between peoples' willingness to pay for each unit of a good or service and what it costs society to make it. A nonmarginal change in a market good cannot be valued at the price because the price itself changes with large changes in the status quo. Nonmarginal changes in market goods are measured by the change in net consumer and producer surplus. For goods and services that are not traded in markets, other economic techniques, theoretically consistent with market prices, or demand and supply functions, must be used instead. These nonmarket techniques are the primary focus of this article.

Economic valuation is anthropocentric. Amenities are beneficial only to the extent that human beings value them. This does not suggest improvements in ecosystem function or other nonhuman effects of a policy have no value. Many people value open space, endangered species, and biodiversity and have shown through their memberships in environmental advocacy groups, votes in local referenda, and donations that they are willing to sacrifice much for these causes. However, the value of an environmental amenity remains what people are willing to sacrifice for that amenity.

Economic value has use and nonuse components. Use values involve an observable interaction between the individual and the environment, including consumptive uses, such as hunting, and nonconsumptive uses, such as hiking. Nonuse value involves no actual interaction between people and the environment. For example, people may value simply knowing that an endangered species (e.g., the panda bear) survives or that a pristine area (e.g., the Arctic National Wildlife Refuge) exists, even if they never plan to see or use such resources (1). Option value is a willingness to pay to have the choice of using a service in the future. Society may have some willingness to pay to preserve a pristine wilderness area, a biodiversity hot spot, or an endangered species, in anticipation of possible future use of such resources. In practice, however, option value has often been confused with expected use and has led to the double counting of values.

The economic concept of value is supported by centuries of rigorous thought, has been applied by legislative and executive mandates to do benefit-cost analyses, and is accepted as a legal basis for natural resource management and damage assessment. What can economics value and what can it not? Economics is good at valuing adjustments on the margin and advising decision makers about trade-offs. Most natural resource policy decisions are marginal, and economic tools are appropriate for measuring such trade-offs. Economics is weaker at valuing all-or-nothing comparisons, such as the existence or disappearance of whole ecosystems. Some analysts have incorrectly attempted to use valuation to measure the all-or-nothing value of ecosystems (2). The elimination of Earth's vital ecosystem services would be catastrophic. Economic valuation is not well suited to assessing the value of the complete destruction of global ecosystems. Such efforts produce a "serious underestimate of infinity" (3).

The magnitude of economic value depends critically on the scale and context of the change. For example, does a dam provide just a small fraction of the electricity in a region or almost all of it? Can it be valued at market prices or is it large enough to change prices? What is the value of fish that may be lost by a dam? Will the change affect only a small part of the fish population or will it eliminate all remaining members? The value of species habitat rises as the amount of available habitat falls, and the value of rivers as sources of electricity rises as electricity becomes scarce. Irrigation water in one place may keep some people alive, but in another, it may be abundant and allocated to lower-valued uses. Because water is hard to transport, the marginal value of water depends greatly on the setting. The cost of removing one dam may be high but another low, depending on available substitutes for what is lost and what is gained. Economic methods are designed to estimate the value of environmental services in specific locations and capture these important locational characteristics.

Economic values also depend on who is valuing them. For goods traded in world markets, everyone buys or sells at the world price, and marginal values are consistent across people. However, for goods that are not traded, values depend on the people affected. For example, the damage from air pollution in one country versus another will depend on the income of the country. People in a poor country have many critical pressures on their scarce resources and so may be unwilling to expend too many resources fighting this single risk. They may place a lower value on air pollution abatement than people in richer countries.

Economics also places a value on time. The choice to save or consume and the choice to invest or not around the planet creates a market interest rate. This interest rate is a value on time. Obtaining services today is worth more than anticipating those same services in the distant future. Policies that delay benefits are worth less than policies that provide benefits more quickly. However, the fact that we all value the present slightly more than the future does not imply we should destroy the planet for immediate gratification. There is every reason to expect that rising productivity will allow future generations to be wealthier than current ones. Prudent decision makers will preserve environmental resources for the future because they will have great value in the future.

Economics depends upon understanding what trade-offs are actually being made in policy. In practice, however, the exact trade-offs are rarely known with precision. What role does uncertainty play? For many small decisions with independent risks, economists measure the expected value of outcomes. Sometimes this leads to an underestimate and sometimes an overestimate of actual value, but these many small errors balance out in the long run. For example, one may regulate many pollutants without knowing exactly the harmfulness of each one. However, there are some uncertainties that have very large magnitudes. The effect of climate change in the long run is a good example. After one or two centuries of uncontrolled greenhouse gas emissions, the consequences may be manageable or unmanageable. Society may want to value such risks at more than the expected value of the outcomes, adding a "risk premium" because such risks cannot be balanced by any current action. In practice, few environmental decisions lead to big enough risks to justify risk premiums.

Economists engage in valuation of environmental amenities for many reasons. First, benefit estimates are an important input to the design of efficient environmental policy. Many environmental goods and services are "public goods"; enjoyment of such goods by one person does not interfere with the ability of others to enjoy them, and no one can be excluded from consuming public goods, whether they pay or not. Examples include natural wonders like the Great Barrier Reef, an intact stratospheric ozone layer, and a stable global climate. Free markets underprovide these valuable goods. Even when markets form, they cannot fully capture the value of public goods. Because people will enjoy these services even if they do not pay for them, there is a temptation to free ride on others' contributions. Some people care more about the good than others. It is therefore difficult to devise a scheme to charge people and difficult for people to agree on how much of the service to purchase. Governments must intercede with management, regulation, and incentives to provide and protect public goods. Governments must know how valuable these goods are to people because scarce public dollars must be spent on their protection. In some cases, the law actually requires benefit-cost analysis of environmental policy. Valuation provides benefit estimates critical to this process.

Second, in the context of litigation, economic valuation methods are recognized as legal means of natural resource damage assessment (for the purpose of determining compensation) by institutions, such as the Environmental Liability Directive of the European Union, and U.S. laws, such as the Clean Water Act (CWA); Comprehensive Environmental Response, Compensation, and Liability Act (commonly called Superfund); and the Oil Pollution Act. Some countries have begun the process of integrating natural resources and environmental amenities into estimates of the value of goods and services produced by an economy, such as gross or net national product, which is called environmental or "green" accounting. Economic valuation techniques are a critical component of this effort, as well.

Outside of the policy context, economists value environmental and resource amenities (or disamenities) to further refine the statistical and survey methods used to derive estimates. Finally, many valuation studies may be performed to draw attention to the significant values of ecosystem services when the failure to generate such estimates often results in an effective value of zero. The Millenium Ecosystem Assessment is a good example of this phenomenon.

The comparison of benefits and costs can increase social welfare by identifying policy interventions with net benefits. However, any policy intervention creates winners and losers. Electricity consumers may bear significant costs from the removal of a nearby dam, whereas conservationists may benefit from knowing a fish population is preserved. If net benefits rise from dam removal, the winners could compensate the losers. But such compensation rarely takes place. Valuation provides valuable information about who gains and who loses from an environmental policy intervention. Economics estimates the compensation necessary to bring losers back to their original level of well-being. But economic analysis stops short of normative recommendations about who should win or lose from environmental and resource policies and whether compensation should occur. Compensation is a policy decision that remains in the hands of political decision makers.

In this article, we provide a careful review of selected literature on valuation for an audience of noneconomists. The second section of this review describes the practice of valuing environmental benefits using a variety of techniques developed over the past four decades. We examine the assumptions and methods of a set of valuation techniques, discussing the strengths and weaknesses of each approach [additional reviews of valuation can be found in Freeman (4), Mäler & Vincent (5), and Bockstael et al. (6)]. In Section 3, we discuss selected applications of these methods to environmental goods and services; both pollution policies and natural resource management are covered. We conclude in Section 4.

2. METHODS FOR VALUING THE ENVIRONMENT

Two broad classes of methods can assess the economic value of environmental amenities and disamenities in the absence of explicit markets: behavioral (revealed preference) methods and attitudinal (stated preference) methods. Revealed preference methods seek natural experiments to estimate the demand function for an environmental good. Researchers look for cases where people face exogenous differences in environmental prices and the available quantity of goods; the relationship between price and quantity can be estimated by observing consumers' choices in these situations. However, because the experiments are usually not randomized, the methodologies must control undesired variation using a combination of carefully choosing experiments and controlling for remaining problems with statistical techniques. Some revealed preference techniques lean more heavily on structural statistical models, and their attendant assumptions, to estimate values. Other techniques, often called quasi-experimental methods, lean more heavily on the assumption that policy interventions are truly exogenous and have created something close to a randomized experiment in a natural setting (7). Both approaches have strengths and weaknesses (8).

Stated preference, or attitudinal, methods ask consumers how much they value environmental goods and services in carefully structured surveys. The approach has the appealing virtue that it can be used to value any environmental good or service as long as the good can be described. Because the approach is not tied to behavior, it can be used to value some goods and services that revealed preference methods cannot value. However, in practice, the survey methods are more difficult than they appear.

Economists have a professional bias toward revealed preference approaches because economic science has developed around observing choices agents make in markets. The social sciences, in general, do not have this prejudice as sociologists, psychologists, and political scientists often apply attitudinal methods. However, as observed in social psychology, what people say they would do and what they actually do may differ. This raises several problems with stated preference methods, discussed below. Thus, economists generally rely primarily on revealed preference approaches to estimate use value and reserve stated preference methods for nonuse value and to assess peoples' value for states of the world that do not exist (e.g., estimating the value of a piped water connection where there currently is none).

2.1. Revealed Preference Methods

Many environmental goods are inputs to production processes. Even if these inputs are not readily traded, their value can be calculated indirectly through market analysis. For example, the value of nontimber forest products, such as fruits, latex, and tropical medicines in a hectare of forestland, can be calculated by measuring the net revenues from collecting these goods per hectare (9). Alternatively, the damage from sea level rise can be measured using the market value of land that is inundated plus the cost of constructing protective sea walls (10).

One can also measure the value of environmental factors that cause the demand or supply

RUM: random utility maximization

of a market good to shift. For example, one can look at the impact of climate change on energy by observing how climate shifts demand functions for energy resources (11). Similarly, a shift in water supply can be valued using a demand model of water consumption in a watershed (12). The change in net consumer surplus across all users is the change in value.

2.1.1. Travel cost models. Although access to many environmental and resource amenities requires an entrance fee, that fee is often small compared to the expense of traveling to these sites. Harold Hotelling suggested the "travel cost method" of valuation that exploits the variation in travel cost to a site (an implicit price) that arises when people travel from different origins. Exploiting the empirical relationship between travel cost and visitation rates permits the estimation of a demand function for recreation (13, 14).

The demand for any good or service is, in part, a function of the prices of substitutes and complements; this is also true of environmental goods and services. Economists recognized shortly after the original travel cost model was developed that consideration of substitute sites would be important and introduced models involving systems of demand equations in which demand could be simultaneously estimated for multiple sites (15).

The economic value of recreation at a site also depends on site characteristics, including environmental quality (e.g., water quality at a beach, air quality at a national park where scenic views are valued, and the average catch by anglers in a river). One can use multiple site models to value site characteristics if the only difference between two sites is the characteristic in question (16). However, in practice, sites differ in many characteristics.

Discrete choice methods model the choice of a site by a visitor as a function of site characteristics (17). People choose different sites to obtain different packages of site characteristics. One can value site characteristics by seeing what travel costs people would pay to obtain different packages. Such models can be estimated using random utility maximization (RUM) models (18). Within this framework, the consumer chooses the recreational site (if any) that maximizes her utility, which is a function of income, the prices of the chosen site as well as those not chosen, and the characteristics of the site chosen and those not chosen. The researcher has many specification decisions to make regarding the definition of the limited choice set (i.e., which sites are appropriately considered substitutes), the structure of econometric error terms, the treatment of unobserved consumer heterogeneity (i.e., preferences), and many other factors (19). Statistical development of the RUM travel cost models has given rise to one of the most active and prolific literatures in economic valuation.

Travel cost models are among the most widely applied valuation methods and have become a very useful tool for estimating recreational demand, an important component of total value for many resource amenities. But there are some challenges to these methods. Like all statistical models, they are vulnerable to the possibility that important factors have been omitted, which could bias the results. Other challenges stem from the fact that actual travel cost, or some portion of it, may be unobservable (20). One key unobserved cost is the opportunity cost of travel time. Some authors suggest assigning the wage rate to value time (21), but empirical evidence suggests that people enjoy traveling (22), suggesting a lower value. Researchers must also consider how to value time spent at the recreational site (23).

Another important issue concerns multipurpose trips. Some people travel just to visit a single recreational site. For trips with multiple purposes, however, an individual recreation site represents only a portion of the trip's value. If the analyst drops multipurpose trips, it will bias downward the site's value. Assigning proportional values to each destination or purpose is, unfortunately, arbitrary.

Many of the assumptions of travel cost models can be dealt with through sensitivity analysis. Researchers can make a range of assumptions about the opportunity cost of time, which travel expenditures to include, and what portion of costs for a multipurpose trip should be attributed to an individual site. They can then observe how the recreational value of a site changes with these changes in assumptions.

2.1.2. Hedonic property models. Hedonic models arise from the idea that the price of a good is really a sum of the implicit prices of each of its characteristics. For example, the price of a car comprises the implicit prices for characteristics including fuel efficiency, acceleration, passenger seating, and aesthetic appeal. Similarly, the price of a home depends on several groups of characteristics that determine its value: (*a*) physical structure, such as the number of bathrooms and bedrooms and square footage; (*b*) characteristics of the surrounding neighborhood, e.g., the quality of public schools, proximity to jobs and transportation networks; and (*c*) environmental amenities, such as air and water quality or proximity to open space. Hedonic property models collect data on the prices of home sales and housing characteristics, like those listed above, and then estimate the marginal implicit prices of the characteristics of interest. This captures the marginal value of an environmental amenity to homeowners at the amenity's current level of provision. Hedonic models have been used primarily to estimate the economic value of air quality (24, 25). Other environmental applications include proximity to wetlands and open space and disamenities such as hazardous waste sites and airport noise (26).

Though valuable in many settings, hedonic property models have limitations (27). First, the researcher must assume that buyers and sellers have good information on the characteristics of all housing alternatives. Thus, the models are appropriate only for estimating the value of observable or known amenities and disamenities. Second, the models assume that people are mobile enough that current prices reflect their preferences.

Although the hedonic methods readily estimate the marginal value of site characteristics, it has also been suggested that the technique can be used to estimate the demand for characteristics (28). Several authors have attempted to estimate the demand for characteristics using data from a single market. Unfortunately, the variation in the observed prices in a single market is perfectly correlated with the variation in demand shift variables across people, so the demand functions cannot be estimated (29, 30). Some authors have sought to overcome this by segmenting housing markets within a single city, but this approach requires strong assumptions (31).

The unobserved characteristics of housing consumers cause people to self-sort into neighborhoods on the basis of their preferences for environmental quality (32–34). As with all natural experiments, unobserved factors can be spatially correlated with environmental quality, leading to biased estimates. For example, higher levels of air pollution may be observed in urban areas that also have more jobs. More jobs, in turn, can increase housing values. If one fails to adequately control for such factors, one may over- or underestimate the price of air pollution.

Another application of the hedonic property approach is the Ricardian model of agricultural land. Regressing farmland value on climate and other control variables, this approach can estimate the impact of climate on farmland value, using both cross-sectional (35) and panel data (36).

2.1.3. Hedonic wage models. Hedonic wage models share a similar theoretical basis with hedonic property models. In environmental economics, these models are used primarily to value mortality risk. Jobs are collections of characteristics: training, education, fringe benefits, prestige, and working conditions, including the risks of accidental death or injury (37, 38). Regressing wages on job characteristics (controlling for worker characteristics) reveals their marginal implicit value. For example, the coefficient on the risk of a fatal accident reveals how much additional compensation a person requires to assume an additional small risk.

VSL: value of a statistical life

These estimated values of small risk reductions have been translated into the value of a statistical life (VSL). For example, imagine that 10,000 people are employed in a risky occupation, each faces a 1/10,000 risk of death, and each is willing to pay $500 to eliminate this risk. The total willingness to pay for risk reduction would be $5 million, which would prevent one statistical death, so this is the VSL. This technique does not estimate the compensation required for certain death or illness; it simply provides a measure of the rate at which workers are willing to trade fatal and nonfatal risk for monetary compensation.

Viscusi & Aldy (39) review the economic literature on valuing risks to life and health. There are several challenges to this approach. As in the hedonic property models, omitted variables are a serious concern. For example, some people are insured by either private insurance or workers' compensation. They, or their heirs, consequently will receive a payment in case of their death or an accident. If this payment is not included, the hedonic wage approach could underestimate the value of risk (40). Omitted variables that are correlated with both wages and risk (such as unobserved characteristics of the worker, e.g., ease of work under pressure, or of the job, e.g., physical exertion) are particularly problematic. In addition, many jobs involve correlated risks of different types of injury, as well as fatality. Attempts to value small risk reductions for each of these occurrences must control appropriately for changes in the other risks, or estimates will be biased. The "sorting" effects that have begun to be addressed in the hedonic housing models are also relevant to hedonic wage models (41).

The hedonic wage approach can only estimate the value of changes in risks that workers perceive accurately. The probability of injury or death on the job may not be accurate. For example, people might think that being a police officer or fire fighter is dangerous, but statistics show these jobs are quite safe (42). Researchers themselves may have trouble measuring mortality rates. For example, it may not be clear whether a heart attack on the job was actually caused by the job.

There is evidence that the marginal value of risk may vary with age (43, 44), across countries (45, 46), and with the character of the risk, such as latency (47). For example, people may value the risk of cancer differently from the risk of a sudden car accident. The hedonic wage literature tends to measure the value of reducing accidental deaths and not deaths associated with long-term chronic exposure to environmental contamination, but long-term chronic risks dominate the risk of accidental deaths on the job. Miners may die from black lung disease, bakers from white lung disease, and farmers from long-term exposure to particulates. These risks with long delays actually resemble the risks associated with pollution. Unfortunately, the literature is limited by the near absence of reliable estimates of long-term mortality risks by occupation.

2.1.4. Averting behavior models. If people incur private expenditures to avoid the damages from pollution or other environmental disamenities, the sum of these incurred costs is at least a partial estimate of the value of these damages. In economic terms, these are "avoidance costs" or "averting expenditures." For example, if a groundwater source is contaminated, people may substitute bottled water. One can consider the medical costs a person incurs to treat any illness caused by pollution exposure in a similar way. Averting expenditures and "cost of illness" measures, however, are at best a lower bound on the value of damages from pollution because they do not capture the pain and suffering that cannot be avoided (48).

2.2. Stated Preference Methods: Contingent Valuation

Attitudinal methods use carefully designed surveys that ask consumers how much they value environmental goods and services. The survey creates a hypothetical market for the amenity so that responses can be evaluated in a manner similar to behavior observed in markets. The basic architecture of a contingent valuation (CV) survey is (*a*) a description of the service/amenity to be valued and the conditions under which the policy change is being suggested, (*b*) a set of choice questions that ask the respondent to place a value on the service/amenity, and (*c*) a set of questions assessing the socioeconomic characteristics of the respondent that will help in determining what factors may shift that value (49).

CV: contingent valuation

Stated preference methods can be used to value any environmental good or service, even at levels of quality that are currently not in existence. They can also capture nonuse value, which cannot be measured using revealed preference methods. Nonuse values may be the largest, most important social values in some policy contexts, such as endangered species and wilderness preservation. Economists debate over whether such values should be included in economic analyses (50, 51). We focus here on describing stated preference methods, rather than examining the validity of nonuse value in economic theory. Nonetheless, there is an important paradox; some of society's most important values for natural resource amenities may be precisely the values that we have the least confidence in measuring.

In early attitudinal surveys, researchers simply asked people how much they were willing to pay for each amenity; this has become known as an "open-ended" question design (52). However, such open-ended valuation questions are limited in their ability to provide accurate results. Close-ended discrete choice questions, in which respondents offer a "yes or no" response when offered one or more specified prices for an environmental good or service, have largely replaced open-ended questions in CV studies. This newer format requires households to exercise the kind of judgment more familiar to them from typical purchases (53).

CV survey respondents may lack market experience with the environmental good and not understand how to value it (54). Respondents sometimes express the same value for environmental goods of very different magnitudes. For example, the valuation of responses to the loss of 2,000, 20,000, and 200,000 migratory waterfowl in the Central Flyway was essentially the same (55). In other cases, analysts have noted appropriate sensitivity to scope (56, 57). It may be that such results, inconsistent with economic theory, are directly attributable to survey design problems and can be avoided in practice (58).

CV survey respondents may also be swayed by how a question is framed (52, 59). For example, one can describe the impact of an oil spill on local fishermen in purely scientific terms by measuring the fish lost. Or one could choose to also convey the many precautions that the oil industry took to avoid a spill and that oil development was part of a national energy independence effort. Alternatively, one could mention that the captain of the vessel that caused the spill was drunk, the oil company was making huge profits, and the fishermen were poor. These details greatly influence responses, leading to very different values.

Respondents may also be affected by how they are asked to pay for the environmental good. For example, many respondents care whether the payment comes in the form of taxes, fees, or contributions. Respondents sometimes protest the question because they object to the payment method. They may provide "protest zeros," even though they may actually have some positive value for the good. Although some studies simply drop observations that respond poorly to preliminary questions, it is better to control for protestors but still include them as part of the sample (60).

A final problem with attitudinal surveys is that the responses to willingness-to-accept (WTA) questions have generally been many times greater than the responses to willingness-to-pay (WTP) questions (61). This is especially true for nonuse values (62). These large differences are difficult to justify, suggesting they are measurement problems.

A Report of the NOAA Panel on Contingent Valuation developed a set of guidelines to suggest best practices for CV surveys (63). To help respondents understand the good, the report suggested an extensive unbiased description of the good. It also recommends the use of close-ended questions and the use of WTP questions rather than WTA questions. In addition, experimental economics has contributed significantly to survey design in recent years (64, 65). Well-designed CV surveys are, for now, the only tools available for estimating nonuse value. They have also been used to estimate some types of use value; for example, they have been used in mortality risk valuation (in many cases obtaining estimates comparable to those from hedonic wage studies), as well as in estimating the value of improving piped water service coverage and increased provision of vaccines in developing countries.

3. APPLICATIONS OF ENVIRONMENTAL VALUATION METHODS

The methods reviewed in Section 2 have been applied to a wide variety of environmental and resource management problems. This section reviews applications to local and global air pollution, water pollution, solid and hazardous waste, and the use and management of natural resources, including water, wetlands, forests, species, and biodiversity.

3.1. Valuing Pollution Emissions and Abatement

Numerous studies have now measured pollution damages in the United States. Existing studies probably capture the majority of pollution damages in the United States. The only obvious weakness in the U.S. studies is that the studies do not capture the impacts in every location. There are still places where at least some pollution emissions remain unstudied. In contrast, the damages from pollution outside of the United States have been analyzed in only a few contexts. Thus, one of the major tasks still facing valuation is to obtain values across the world.

In order to measure the damages from pollution emissions, emissions must be linked with final consequences, using integrated assessment models to capture emissions, dispersion, exposure, physical response, and valuation of those responses. Thus, one task facing economists is to link what is known about the economics of pollution (emissions and valuation of effects) to what is known about natural science (atmospheric science, atmospheric chemistry, hydrology, epidemiology, and toxicology) in a coherent model. Recent advances in these methods have made it possible to value not only large changes in emissions (66, 67) but also marginal damages (68). Of course, there remains a great deal of uncertainty in such modeling efforts. Furthermore, it is critical that the links between science and economics be made carefully.

3.1.1. Local air pollutants. Many analyses have estimated the value of reducing local air pollutants. Most of the benefits estimated by the U.S. Environmental Protection Agency (EPA) from federal air quality regulations suggest human health benefits—reduced morbidity and mortality—comprise the vast majority of benefits. The EPA uses a VSL estimate based on an analysis of 26 different economic estimates (5 CV and 21 hedonic wage studies), applying a mean value of US$(1999)6.2 million, adjusted for inflation (69). The EPA also adjusts VSL values to account for latency (the lag between exposure and outcomes) and for income growth over time. Because of equity concerns, the EPA is barred by the U.S. Congress from adjusting VSL by age (69). The literature has also estimated the economic value of avoided illness (70, 71). Alberini & Krupnick (72) summarize the valuation estimates for avoided illness and deaths used in four major models by regulatory agencies in the United States, Canada, and Europe.

Lead is a local air pollutant with very significant abatement benefits. In a 1985 report, the EPA quantified the main benefits of reducing lead in gasoline: reduced human health damages from lead exposure (retardation of children's cognitive and physiological development and exacerbation of high blood pressure in adult males), reduction in other local air pollutants from vehicle emissions (because leaded gas destroyed catalytic converters, designed to reduce emissions), and lower costs of engine maintenance and related increases in fuel economy (73). The net benefits of the lead phase down were more than US$(2008)15 billion/year.

Another local air pollutant regulated in many countries is sulfur dioxide (SO_2). The 1990 Clean Air Act (CAA) amendments in the United States reduced SO_2 emissions from older power plants by 10 million tons per year, in aggregate. Burtraw et al. (74) used estimates from the economics literature of the monetary value of these effects (primarily from CV studies, in this case) to estimate total health benefits, and a RUM travel cost model to estimate the value of improvements in Adirondack lake fishing attributed to decreased acidification. Changes in visibility at two national parks and in five eastern U.S. cities were estimated using CV studies. The study suggested benefits of US$(1990)3300/ton and costs of US$(1990)270/ton (74). Reduced incidence of illness and mortality in the Northeast United States comprised 85% of the total estimated benefits.

Most of the benefits from reducing SO_2 emissions are attributable to the resulting effects on particular matter (PM) concentrations. Smith & Huang (75) performed a meta-analysis of hedonic property estimates of the value of reducing PM_{10} concentrations. They compared the values obtained from using VSL estimates of health benefits with the benefits from the hedonic property studies. (Such estimates are not directly comparable. To the extent that homeowners correctly perceive the health effects of PM, we would expect some of the total health effects of the policy to be incorporated into hedonic property estimates, though only effects for homeowners. In addition, the hedonic property estimates include other benefits, such as visibility improvements.) The health benefits were $8.6 million in Anaheim, California, and $781 million in Los Angeles, California, whereas the hedonic property study measures were $1.7 million and $76 million, respectively. Chay & Greenstone (33) suggest increases in housing values that are between these two estimates.

The literature also includes comprehensive analyses of the benefits of the CAA, taking all local pollutants into account. Freeman (76) estimates the value to be about $47 billion/year, the EPA (66) estimates the value is $70 billion/year, and Muller & Mendelsohn (67) estimate the value to be between $48 and $277 billion/year depending on the values assigned to human health. Human health effects comprise about 94% of these damages.

3.1.2. Ozone-depleting chemicals. Economic analysis of the benefits of phasing out the use of chlorofluorocarbons (CFCs) and other stratospheric ozone-depleting chemicals supported the U.S. decision to agree to the Montreal Protocol (77). Benefit-cost analysis estimated significant net benefits from unilateral U.S. action to curb the production and consumption of CFCs, with even larger net benefits from international action (78). The EPA's estimates of the human health benefits of the U.S. achievement of its Montreal Protocol obligations included avoided cases of skin cancer mortality and morbidity as well as cataracts. The EPA also estimated the benefits of avoided crop damage from UV-B radiation and ground-level ozone, reductions in the commercial fish harvest, and damage to outdoor plastic materials. Avoided skin cancer mortality, alone, comprised 98% of these monetized benefits.

3.1.3. Greenhouse gases. Extensive research has been done on the impacts of greenhouse gases, especially impacts on agriculture. Crop studies and crop yield models suggest that the yields of many grains would fall if grown in a warmer setting (79). Some Ricardian studies suggest that net revenues from dryland crops will be very sensitive to warming (80, 81). By contrast, crop economic models suggest that farmers will switch crops, and prices will adjust so that the welfare impacts will be quite small in the United States and possibly even beneficial (82). This is supported by Ricardian studies of the United States as well (35). Ricardian studies in Africa (81) and Latin America (83), however, suggest warming will lead to crop damages.

Other important potential effects of climate change that have been valued include sea level rise (coastal flooding) and impacts on energy use, water resources, and forestry. The key to obtaining accurate measures of the impacts of all these effects is to include adaptation. For sea level rise, it is important to adapt as the sea rises over time. If sea walls are built to accommodate rising oceans over time, the present value of protection is quite low (10, 84), and all developed coastline is protected. There are benefits to warming in reduced heating costs as well as damages from increased cooling costs. When measured in British thermal units, these effects are similar. However, it is more expensive to cool homes, and more homes are expected to require cooling over time, so warming causes net damages in the energy sector (11). The primary damage to the water sector is the expected reduction in flow, which will reduce supplies to irrigation (12). The direct effect of warming on forest productivity is expected to be beneficial, so that forest impacts are slightly positive (85).

3.1.4. Water pollutants. Reducing human illness and deaths by providing clean drinking water sources is a policy intervention with very significant net benefits. Piped, treated drinking water provision in major American cities during the early twentieth century resulted in large reductions in urban mortality, with an estimated social rate of return to infrastructure investments of 23 to 1 (86). Improvements in access to clean drinking water in Brazil between 1970 and 2000 resulted in a welfare gain of $7500 per capita (87). Where households must fetch water outside of the home, the benefits of piped drinking water supplies include the opportunity cost of the time previously spent gathering water. Numerous CV studies have demonstrated that poor households in developing countries lacking safe drinking water sources are willing to pay significant sums for their provision (88, 89). That is not to say that all drinking water quality improvements have net benefits. If drinking water quality is already safe, increasing the stringency of drinking water standards may have net costs. For example, two recent standards promulgated under the U.S. Safe Drinking Water Act, i.e., new standards for arsenic and radon, had net costs (90, 91).

In contrast to drinking water standards, ambient water quality standards, where raw water is not directly consumed, have low human health benefits. Most of the benefits of such policies have to do with recreational use and ecosystem health. A number of studies have estimated the benefits of the CWA and its amendments. Using travel cost studies and CV analyses, Freeman (76) estimates recreational benefits (freshwater fishing, marine sports fishing, boating, swimming, and waterfowl hunting), indirect use benefits (aesthetics, ecology, and property value), commercial fishery benefits, and cost reductions for water treatment in municipal, industrial, and residential settings. He reports a best estimate of total benefits of $(1996)22.6 billion per year. Carson & Mitchell (92) perform a single comprehensive CV analysis, asking a national random sample of U.S. households to value the change in water quality that results from moving from no pollution control to "swimmable" water quality nationwide. Their best estimate of annual benefits is $(1990)29.2 billion. Lyon & Farrow (93) build on these studies, as well as others in the literature, to assess the incremental benefits of additional water pollution control investments beyond 1990. In sum, these three studies suggest that the CWA had significant net benefits between 1972 and the late 1980s, but that at some point around 1990, incremental costs of additional abatement began to exceed incremental benefits.

There are also many estimates of the value of water quality improvements on a smaller scale. For example, economists have shown that residential waterfront land prices increase with reductions in fecal coliform contamination (94), that consumers have significant willingness to pay for coastal water quality resulting from reductions in nutrient runoff (95), and for improvements in beach water quality (96). Recreational fishing benefits of water pollution abatement have also been assessed at many individual sites (97, 98). There are an increasing number of developing country applications in the literature; Day & Mourato (99) use a CV survey to estimate the value of improvements in river water quality in China, and Choe et al. (100) estimate the benefits of reducing surface water pollution in the Philippines using both CV and travel cost models. However, studies in developing countries remain sparse.

3.1.5. Solid and hazardous waste. The U.S. Comprehensive Environmental Response, Liability and Compensation Act (Superfund) regulates the cleanup of sites contaminated with toxic wastes, and it has been well studied by economists. One estimate of the benefits of site cleanup at 150 sites, in terms of monetized reductions in cancer risk, suggests an average cost per avoided cancer case that is low relative to most VSL estimates (101); however, these benefits are unevenly distributed. There are very high benefits of cleaning up a small number of sites, but 70% of studied sites have an estimated cost of reducing cancer risk exceeding $100 million per death, more than an order of magnitude higher than the likely benefits. Hedonic housing price models near Superfund sites indicate households are willing to pay values similar to VSL estimates from hedonic wage and CV studies (102).

Several hedonic housing price studies have assessed the disamenity value of Superfund sites. These studies estimate that willingness to pay varies with distance from listed Superfund sites (103), that housing prices decline once Superfund sites are listed (104), that housing appreciation rates are lower near Superfund sites (105), and that values increase when sites are cleaned up (106). Smaller contaminated sites (not listed as Superfund sites) have also been shown to impact nearby residential and commercial property values (107). In contrast to this literature, Greenstone & Gallagher (108) find negligible impacts of Superfund sites on residential property values and rental rates. A recent comprehensive analysis suggests that the impact on local property values varies spatially and is highly localized (109).

3.2. Valuing Natural Resource Amenities and Ecosystem Services

The marginal value of many natural resources that are exchanged in markets is captured by their price. Nonmarginal values of changes in marketed goods are captured by the change in consumer and producer surplus. Market prices may not reflect true economic scarcity if prices are distorted by open access and externalities (110). For example, the extraction of many natural resources changes the ecosystems around them. These changes may not be borne by the extractor and so are not reflected in market prices.

Prices are readily available for market goods, but values for natural resources not traded in markets are often missing. The science of valuing nonmarket goods and ecosystem services in recent years has advanced, but the most important need going forward is better integration of economic models with models from the natural and physical sciences. The value of an ecosystem intervention depends upon how it changes final ecosystem services. Progress in this field has been slow because it has not been easy to identify final ecosystem services. One confusion lies between intermediate and final services. For example, plant productivity is an important intermediate service because it contributes to final services, such as additional timber and more abundant wildlife. An additional complication is that what society might value most about an ecosystem may be poorly connected to anything scientists measure. For example, people might like the impression of wildness or the aesthetics of a site, but that might not be measured in net primary productivity, diversity measures, or stock density.

Ecological production functions can predict outputs of ecological services, given ecosystem structure and function. Anticipated changes in structure and function can then be modeled, and changes in ecosystem service outputs valued (111). Our ability to estimate such functions is limited by our "imprecise understanding of ecological processes, complex interaction among ecosystem processes, and lack of data" (112). Nonetheless, in many cases, scientific understanding is sufficient to obtain reasonable estimates of economic values. Recent work has combined valuation of multiple ecosystem services (113) and developed spatially explicit models using the ecological production function approach (114, 115). The ecosystem services literature combining economics and ecology in this way is in its infancy, and advances in this area will have high value for ecosystem service valuation in the future. In this section, we do not pursue valuing interventions in ecosystems, but focus on describing studies that have valued the final goods and services of ecosystems.

3.2.1. Water resources. Prices transmit information about the economic value of marketed goods, but true markets for water are rare. Because markets do not establish water prices, they cannot be used to determine the economic value of water in its various uses. Water resources are natural assets that provide service flows used in the production of goods and services, such as agricultural output, human health, recreation, and more amorphous goods, e.g., quality of life. As with physical capital, deterioration in water quality or quantity (as a productive asset) reduces the flow of services a water resource is capable of providing. The methods used to value water depend upon the type of use. Water markets tend to be specific to water basins because it is very expensive to move water from one basin to another. Depending on the availability of dams in a system to store water, there can also be large differences in the scarcity value of water over the year.

Estimating the value of the quantity of water in residential use requires the estimation of a demand function for water (116). One can then integrate over different portions of the demand curve to estimate the economic benefit derived from water consumption at different levels of use.

For industry and agriculture, one must model an input demand function that maximizes profit given a particular production process. The marginal value of water can be measured by the increase in profits from a one-unit increase in water inputs. Because production data are sometimes more difficult to obtain than residential consumption data, estimating the demand functions in these sectors can be more challenging (49, 117). Even when data on piped water are available, many plants have additional water sources from raw water and recycling. There are consequently few industrial water demand studies (118). The metering issue is even more severe for agricultural water consumers. Farmers who withdraw water directly from surface sources usually do so for free. Many agricultural water demand curves are estimated for groundwater, often using energy costs to construct a water price variable (because groundwater must be pumped to the surface). Prices can also be obtained where farms purchase water from irrigation districts or other water management institutions. Although the economics literature contains many agricultural water demand estimates, the quality of the data is always an issue. Hedonic methods have also been used to isolate the portion of agricultural land prices that can be attributed to water supply of a particular quality and quantity (49, 119).

Estimating the value of instream water for recreational use or ecosystem maintenance requires recreational demand models or CV. Spatial and temporal dimensions are particularly important. For example, the economic values of water instream for recreational fishing, the health of fish habitat, and recreational rafting have been shown to vary seasonally (120). The value of recreational fishing also depends on fishery management policies (121). Unlike the value of water withdrawn for residential, industrial, and agricultural activity, water instream is associated with both use and nonuse values. Studies indicate that individuals hold significant value for the maintenance of flow in surface water systems with major recreational use and systems that support endangered species habitat (122).

3.2.2. Wetlands. Wetlands are classic public goods. They provide a rich set of ecosystem services, many of which are public goods. In part due to their rapid depletion in industrialized and, increasingly, developing countries by conversion to agricultural and urban use, they have been the focus of many economic valuation studies, summarized in a recent meta-analysis (123). Economists have valued a range of biophysical and social functions of wetlands, including their contribution to the maintenance of coastal and marine fisheries for subsistence and commercial use (124). The value of wetlands' functions in recharging groundwater aquifers (125) and wastewater treatment (126) have also been estimated. Travel cost models have been used to value wetlands' recreational value for hunting, fishing, and wildlife watching (127–129). Economists have used hedonic property models to value the aesthetic benefits of wetlands through their contribution to home values (130).

3.2.3. Forests. Forests provide flows of market and nonmarket goods and services with economic value. Market goods include timber and nontimber forest products. The market value of timber can be observed in world prices. The value of nontimber forest products has only recently become known because these markets tend to be local. Economists have valued flows of nontimber forest products using market analyses of the net revenues of collection. The values of fruit and latex in Belize (9); firewood, cork, fodder, mushrooms, and honey in the Mediterranean (131); and many other nontimber forest products have been shown to be significant. The harvesting of products, such as berries and mushrooms, for noncommercial purposes has also been valued using travel cost models (132).

Recreation is an important nonconsumptive use of forest resources, and several studies use travel cost and CV models to estimate the value of forest recreation (133). Other nonconsumptive uses whose value has been estimated include watershed protection (134) and pollination services for local agriculture (135). Carbon sequestration is also an important nonconsumptive use (136). Should a global carbon market arise, this service may have significant market value. Forests also may have significant nonuse value to society at both the local and global scale (137, 138).

3.2.4. Individual species and biodiversity. The economic value of individual species and biodiversity as a whole have both use and nonuse components. Commercial and recreational uses, such as fishing and hunting, generate economic value. Rare or endangered species may create opportunities for ecotourism in the form of wildlife watching (139), more for charismatic species than for plants or invertebrates. An additional aspect of the use value of preserving individual species and biodiversity has to do with their value as potential sources of new pharmaceuticals. There are many well-known examples of life-saving chemical compounds derived from wild organisms, and such compounds are of high value to society. Nonetheless, the expected value that any one species may contribute to a medical breakthrough is low, so this is not a large private conservation value (140).

Perhaps the largest component of the economic value of preserving species and biodiversity is nonuse value (141). CV studies have demonstrated significant willingness to pay for the preservation of endangered species, such as the northern spotted owl (142), the giant panda (143), and the whooping crane (144). Most nonuse value is associated with charismatic species. However, people may be willing to pay for the preservation of less appealing species (plants, invertebrates), and even for specific aspects of ecosystem function, especially where the survival of charismatic species depends on them or where they are strongly linked to other aspects of the landscape that people value (145). For example, CV studies have recently demonstrated willingness to pay for preserving the habitat of the Riverside fairy shrimp in California, which requires reducing development pressures (146), and for habitat defragmentation in protected areas (147). People may also have significant general nonuse value for the preservation of biodiversity (148).

4. CONCLUSION

Many techniques developed over the past 40 years can value the benefits of protecting the environment. Many of the methods focus on observed behavior as policies or other conditions change. These natural experiments take advantage of variation in variables of interest, such as climate and pollution levels, to understand their impact on people and the things they value. However, one of the limitations of natural experiments is that they are not randomized. All the behavioral valuation techniques consequently must pay careful attention to controlling for unwanted variation. The choice of ideal natural experiments is one of the greatest challenges facing empirical valuation studies.

Attitudinal surveys have also proliferated over the past 40 years. Such surveys unquestionably convey that respondents value the environment. Despite their simplicity, it is not clear whether surveys can provide reliable quantitative estimates of the values of environmental goods and services. This is especially true for nonuse values and public good values that can be estimated only with these methods.

It is also important to note that there have been a plethora of valuation studies over the past four decades. Valuation techniques have been applied to many places and issues. Travel cost studies have been implemented across the United States and the world to value recreation. Hedonic wage and property studies have been applied to value the effects of pollution. Economic valuation studies have been done in almost every country to value water. Ricardian studies have been applied around the world to value the impact of climate on agriculture. Of course, not every environmental service has been studied across all locations. One of the remaining challenges facing valuation is the continued application of these techniques to places that have not yet been studied, especially in developing countries.

In the absence of a complete set of valuation estimates, a literature has also developed to transfer benefit estimates (values) across space. Some studies take a simple approach and apply an average value. However, more sophisticated analyses recognize that values vary across space and model what determines values in each location. Meta-analyses have also been conducted to understand whether values vary from one study to the next owing to differences in the underlying true values or to methodological or data differences across studies.

Most valuation studies focus on valuing environmental services in a particular location or calculating a marginal value for a small change in pollution. Analysts involved with "big picture" issues may be concerned that such studies will not capture aggregate effects. Although the benefit estimation techniques we have discussed are well suited to assessing the net effect of specific policies, like reducing air pollutant concentrations and preserving endangered species habitat, they are inadequate to the task of measuring the value of drastic changes in global ecosystems. However, there is a simple way to aggregate values from individual places to a country or even the world. To calculate gross domestic product, we aggregate goods by multiplying local production by price and summing. Similar aggregations can be done with environmental goods provided we have the right prices. For example, with pollution, one can multiply the emissions in each place by their "shadow price" or "marginal damage" and then sum the values across locations (67). This provides an estimate of the aggregate damage using marginal values. Because most pollution choices involve making small changes in emissions, this approach values each small change on the margin. In contrast, looking at the all-or-nothing value of pollution would yield an average value, which may not reflect the margin at all.

Finally, it is important to note that we still do not have comprehensive measures of the value of everything. Some phenomena are very difficult to model and understand, such as extreme events, because they are rare and catastrophic. Other values, especially nonuse values, are difficult, if not impossible, to measure. Estimating a comprehensive value for most natural resource amenities would require the application of many of the different techniques we have described, an undertaking too time-consuming and expensive for many policy contexts, and even then may result in an underestimate of true economic value. In the United States, many such comprehensive analyses have been attempted, particularly for valuing the effects of the major environmental statutes. Globally, however, given the intense focus on valuation in the economics literature (and increasingly, the natural science literature), valuation has been used quite little in public policy analysis (149). Over time, as benefit valuation methods improve, more estimates are generated, and methods for transferring estimates carefully across space are developed, valuation of environmental goods and services may play an even greater role in improving local, national, and international environmental policies.

SUMMARY POINTS

1. The economic benefit of preserving an environmental good or service is what society would be willing to pay for it.
2. Prices measure the value of small quantities of resources traded in markets. The value of large quantities of market goods can be measured using demand and supply curves.
3. For resources not traded in markets, nonmarket valuation techniques must be used.
4. Nonmarket valuation techniques measure use and nonuse values. Use value can be consumptive (hunting) or nonconsumptive (hiking). Nonuse value is less tangible; people may value the existence of an endangered species, for example.
5. Nonmarket valuation methods include revealed and stated preference methods. Revealed preference methods use behavior observed in markets to value environmental goods. Stated preference methods use surveys.
6. Economists typically use revealed preference approaches to estimate use value and stated preference methods for nonuse value.
7. Applications of nonmarket valuation have estimated the benefits of reducing local and global air pollution, water pollution, and solid and hazardous waste. There are extensive estimates of these values for the United States, but fewer for other areas of the world.
8. Valuation of natural resources and ecosystem services has advanced in recent years. The literature includes values for final ecosystem services provided by water resources, wetlands, forests, species, and biodiversity.

FUTURE ISSUES

1. Valuation methods would be strengthened by more interaction between economics and natural and physical science.
2. Nonmarket valuation techniques must be applied to environmental services outside of the United States, particularly in developing countries, paying careful attention to local circumstances. Challenges from scarce data must be overcome.

3. Without a complete set of valuation estimates for policy, economists have begun to develop criteria for transferring benefit estimates across space. The field must explore how to extrapolate estimates from limited studies and apply them to broader areas and contexts.
4. Economic valuation techniques have been misused to assess the value of drastic ecological changes. Careful communication across disciplines regarding the correct use of valuation tools is essential.
5. Stated preference techniques have known limitations yielding reliable nonuse values. This is especially problematic for policy issues such as endangered species or biodiversity preservation, which may have significant nonuse value.

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LITERATURE CITED

1. Krutilla J. 1967. Conservation reconsidered. *Am. Econ. Rev.* 57:777–86
2. Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, et al. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253–60
3. Toman M. 1998. Why not to calculate the value of the world's ecosystem services and natural capital. *Ecol. Econ.* 25:57–60
4. Freeman AM III. 2003. *The Measurement of Environmental and Resource Values: Theory and Methods*. Washington, DC: Resour. Future. 2nd ed.
5. Mäler K-G, Vincent JR. 2005. *The Handbook of Environmental Economics*. Vol. 2: *Valuing Environmental Changes*. Amsterdam: North-Holland
6. Bockstael NE, Freeman AM III, Kopp RJ, Portney PR, Smith VK. 2000. On measuring economic values for nature. *Environ. Sci. Technol.* 34:1384–89
7. Greenstone M, Gayer T. 2009. Quasi-experimental and experimental approaches to environmental economics. *J. Environ. Econ. Manag.* 57:21–44
8. Smith VK. 2007. Reflections on the literature. *Rev. Environ. Econ. Policy* 1:300–18
9. Peters C, Gentry A, Mendelsohn R. 1989. Valuation of an Amazonian rain forest. *Nature* 339:655–56
10. Yohe GW, Schlesinger ME. 1998. Sea-level change: the expected economic cost of protection or abandonment in the United States. *Clim. Change* 38:447–72
11. Mansur E, Mendelsohn R, Morrison W. 2008. A discrete continuous model of energy: measuring climate change impacts on energy. *J. Environ. Econ. Manag.* 55:175–93
12. Hurd B, Callaway JM, Smith JB, Kirshen P. 1999. Economic effects of climate change on US water resources. See Ref. 150, pp. 133–77
13. Clawson M. 1959. *Methods of measuring the demand and value of outdoor recreation*. Resour. Future, Reprint 10. Washington, DC
14. Knetsch JL. 1963. Outdoor recreation demands and benefits. *Land Econ.* 39:387–96

15. Burt O, Brewer D. 1971. Estimation of net social benefits from outdoor recreation. *Econometrica* 39:813–27
16. Kling C. 1988. Comparing welfare estimates of environmental quality changes from recreation demand models. *J. Environ. Econ. Manag.* 15:331–40
17. Morey E. 1981. The demand for site-specific recreation activities: a characteristics approach. *J. Environ. Econ. Manag.* 8:345–71
18. Hanemann WM. 1978. *A methodological and empirical study of the recreation benefits from water quality improvement*. PhD thesis. Harvard Univ., Economics Dep., Cambridge, MA
19. Phaneuf DJ, Smith VK. 2005. Recreational demand models. See Ref. 5, pp. 672–761
20. Randall A. 1994. A difficulty with the travel cost method. *Land Econ.* 70:88–96
21. Bockstael NE, Strand IE, Hanemann WM. 1987. Time and the recreational demand model. *Am. J. Agric. Econ.* 69:293–302
22. Cesario F. 1976. Value of time and recreation benefit studies. *Land Econ.* 52:32–41
23. Smith VK, Desvousges WH, McGivney MP. 1983. The opportunity cost of travel time in recreation demand models. *Land Econ.* 59:259–78
24. Ridker R, Henning J. 1967. The determination of residential property values with special reference to air pollution. *Rev. Econ. Stat.* 48:246–57
25. Harrison D Jr, Rubinfeld DL. 1978. Hedonic housing prices and the demand for clean air. *J. Environ. Econ. Manag.* 5:81–102
26. Palmquist R, Smith VK. 2002. The use of hedonic property value techniques for policy and litigation. See Ref. 151, pp. 115–64
27. Palmquist R. 2005. Property value models. See Ref. 5, pp. 763–819
28. Rosen S. 1974. Hedonic prices and implicit markets: product differentiation in pure competition. *J. Polit. Econ.* 82:34–55
29. Brown JN, Rosen HS. 1982. On the estimation of structural hedonic price models. *Econometrica* 50:765–68
30. Mendelsohn R. 1985. Identifying structural equations with single market data. *Rev. Econ. Stat.* 67:525–29
31. Palmquist R. 1984. Estimating the demand for characteristics of housing. *Rev. Econ. Stat.* 66:394–404
32. Ekeland I, Heckman JJ, Nesheim L. 2004. Identification and estimation of hedonic models. *J. Polit. Econ.* 112(Part 2):S60–109
33. Chay K, Greenstone M. 2005. Does air quality matter? Evidence from the housing market. *J. Polit. Econ.* 113:376–424
34. Bayer P, Keohane N, Timmins C. 2009. Migration and hedonic valuation: the case of air quality. *J. Environ. Econ. Manag.* 58:1–14
35. Mendelsohn R, Nordhaus W, Shaw D. 1994. Measuring the impact of global warming on agriculture. *Am. Econ. Rev.* 84:753–71
36. Deschenes O, Greenstone M. 2007. The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *Am. Econ. Rev.* 97:354–85
37. Thaler R, Rosen S. 1976. The value of saving a life: evidence from the market. In *Household Production and Consumption*, ed. N Terleckyj, pp. 265–98. Cambridge, MA: Natl. Bur. Econ. Res.
38. Viscusi WK. 1979. *Employment Hazards: An Investigation of Market Performance*. Cambridge, MA: Harvard Univ. Press
39. Viscusi WK, Aldy JE. 2003. The value of a statistical life: a critical review of market estimates throughout the world. *J. Risk Uncertain.* 27:5–76
40. Viscusi WK, Moore MJ. 1987. Workers' compensation: wage effects, benefit inadequacies, and the value of health losses. *Rev. Econ. Stat.* 69:249–61
41. DeLeire T, Timmins C. 2008. *Roy model sorting and nonrandom selection in the valuation of a statistical life*. Natl. Bur. Econ. Res. Work. Pap. 14364, Cambridge, MA
42. Moore M, Viscusi WK. 1988. The quantity-adjusted value of life. *Econ. Inq.* 26:369–88
43. Aldy JE, Viscusi WK. 2008. Adjusting the value of a statistical life for age and cohort effects. *Rev. Econ. Stat.* 90:573–81
44. Viscusi WK, Aldy JE. 2007. Labor market estimates of the senior discount for the value of a statistical life. *J. Environ. Econ. Manag.* 53:377–92

45. Liu J-T, Hammitt JK, Liu J-L. 1997. Estimated hedonic wage function and value of life in a developing country. *Econ. Lett.* 57:353–58
46. Alberini A, Cropper ML, Fu T, Krupnick A, Liu J-T, et al. 1997. Valuing health effects of air pollution in developing countries: the case of Taiwan. *J. Environ. Econ. Manag.* 34:107–26
47. Alberini A, Cropper M, Krupnick A, Simon N. 2006. Willingness to pay for mortality risk reductions: Does latency matter? *J. Risk Uncertain.* 32:231–45
48. Harrington WH, Portney PR. 1987. Valuing the benefits of health and safety regulation. *J. Urban Econ.* 22:101–12
49. Young RA. 2005. *Determining the Economic Value of Water: Concepts and Methods*. Washington, DC: Resour. Future
50. Hanemann WM. 1994. Valuing the environment through contingent valuation. *J. Econ. Perspect.* 8:19–43
51. Diamond P, Hausman J. 1994. Is some number better than no number? *J. Econ. Perspect.* 8:45–64
52. Mitchell R, Carson R. 1989. *Using Surveys to Value Public Goods: The Contingent Valuation Method*. Washington, DC: Resour. Future
53. Hanemann WM. 1984. Welfare evaluations in contingent valuation experiments with discrete responses. *Am. J. Agric. Econ.* 66:332–41
54. Carson RT, Hanemann WM. 2005. Contingent valuation. See Ref. 5, pp. 821–936
55. Boyle KJ, Desvousges WH, Johnson FR, Dunford RW, Hudson SP. 1994. An investigation of part-whole biases in contingent valuation studies. *J. Environ. Econ. Manag.* 27:64–83
56. Carson RT, Mitchell RC. 1995. Sequencing and nesting in contingent valuation surveys. *J. Environ. Econ. Manag.* 28:155–73
57. Smith VK, Osborne LL. 1996. Do contingent valuation estimates pass a "scope" test? A meta-analysis. *J. Environ. Econ. Manag.* 31:287–301
58. Carson RT. 1997. Contingent valuation surveys and tests of insensitivity to scope. In *Determining the Value of Non-Marketed Goods: Economic, Psychological and Policy Relevant Aspects of Contingent Valuation Methods*, ed. RJ Kopp, W Pommerhene, N Schwartz, 6:127–63. Boston: Kluwer
59. Hoehn JP, Randall A. 1987. A satisfactory benefit cost indicator from contingent valuation. *J. Environ. Econ. Manag.* 14:226–47
60. Dziegielewska D, Mendelsohn R. 2007. Does no mean no? A protester methodology. *Environ. Resour. Econ.* 38:71–87
61. Knetsch J, Sinden J. 1984. Willingness to pay and compensation demanded: experimental evidence of an unexpected disparity in measures of values. *Q. J. Econ.* 99:507–21
62. Horowitz JK, McConnell KE. 2002. A review of WTA/WTP studies. *J. Environ. Econ. Manag.* 44:426–47
63. Arrow KJ, Solow R, Portney PR, Leamer EE, Radner R, Schuman H. 1993. *Report of the NOAA panel on contingent valuation*. Natl. Ocean. Atmos. Adm., Damage Assess. Restor. Program, Silver Spring, MD
64. Shogren J. 2005. Experimental methods and valuation. See Ref. 5, pp. 969–1027
65. Cummings R, Taylor L. 1999. Unbiased value estimates for environmental goods: a cheap talk design for the contingent valuation method. *Am. Econ. Rev.* 89:649–65
66. US Environ. Prot. Agency, Off. Air Radiat./Off. Policy. 1999. Benefits and costs of the Clean Air Act, 1990–2010. *EPA Rep. to Congress*, *EPA-410-R-99–001*, Washington, DC
67. Muller N, Mendelsohn R. 2007. Measuring the aggregate damages of air pollution in the United States. *J. Environ. Econ. Manag.* 54:1–14
68. Muller N, Mendelsohn R. 2009. Efficient pollution regulation: getting the prices right. *Am. Econ. Rev.* 99: In press
69. Robinson LA. 2007. How US government agencies value mortality risk reductions. *Rev. Environ. Econ. Policy.* 1:283–299
70. Viscusi WK, Magat WA, Huber J. 1991. Pricing environmental health risks: survey assessments of risk-risk and risk-dollar tradeoffs for chronic bronchitis. *J. Environ. Econ. Manag.* 21:32–51
71. Krupnick AJ, Cropper ML. 1992. The effect of information on health risk valuation. *J. Risk Uncert.* 5:29–48
72. Alberini A, Krupnick A. 2002. Valuing the health effects of pollution. See Ref. 151, pp. 233–77
73. Nichols AL. 1997. Lead in gasoline. See Ref. 152, pp. 49–86

74. Burtraw D, Krupnick A, Mansur E, Austin D, Farrell D. 1998. Costs and benefits of reducing air pollutants related to acid rain. *Contemp. Econ. Policy* 16:379–400
75. Smith VK, Huang J-C. 1995. Can markets value air quality? A meta-analysis of hedonic property value models. *J. Polit. Econ.* 103:209–27
76. Freeman AM III. 1982. *Air and Water Pollution Control: A Benefit-Cost Assessment*. New York: Wiley
77. Hammitt JK. 1997. Stratospheric ozone depletion. See Ref. 152, pp. 131–69
78. US Environ. Prot. Agency, Off. Air Radiat. 1987. *Regulatory Impact Analysis: Protection of Stratospheric Ozone*. Washington, DC: US Environ. Prot. Agency
79. Parry M, Canziani O, Palutikof J, van der Linden P, Hanson C, eds. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge Univ. Press. 976 pp.
80. Schlenker W, Hanemann WM, Fischer A. 2005. Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. *Am. Econ. Rev.* 95:395–406
81. Kurukulasuriya P, Mendelsohn R. 2008. A Ricardian analysis of the impact of climate change on African cropland. *Afr. J. Agric. Resour. Econ.* 2:1–23
82. Adams R, McCarl B, Segerson K, Rosenzweig C, Bryant K, et al. 1999. The economic effects of climate change on US agriculture. See Ref. 150, pp. 18–54
83. Seo N, Mendelsohn R. 2008. A Ricardian analysis of the impact of climate change on South American farms. *Chil. J. Agric. Res.* 68:69–79
84. Neumann J, Livesay N. 2001. Coastal structures: dynamic economic modeling. In *Global Warming and the American Economy: A Regional Assessment of Climate Change Impacts*, ed. R Mendelsohn, pp. 132–48. Cheltenham, UK: Elgar
85. Sohngen B, Mendelsohn R, Sedjo R. 2002. A global model of climate change impacts on timber markets. *J. Agric. Resour. Econ.* 26:326–43
86. Cutler D, Miller G. 2005. The role of public health improvements in health advances: the twentieth-century United States. *Demography* 42:1–22
87. Soares RR. 2007. Health and the evolution of welfare across Brazilian municipalities. *J. Dev. Econ.* 84:590–608
88. Whittington D, Briscoe J, Mu X, Barron W. 1990. Estimating the willingness to pay for water services in developing countries: a case study of the use of contingent valuation surveys in southern Haiti. *Econ. Dev. Cult. Change* 38:293–311
89. Pattanayak SK, van den Berg C, Yang J-C, Van Houtven G. 2006. *The use of willingness to pay experiments: estimating demand for piped water connections in Sri Lanka*. World Bank Policy Res. Work. Pap. 3818, Washington, DC
90. Abt Associates, Inc. 2000. Proposed arsenic in drinking water rule regulatory impact analysis. *Rep. EPA 815-R-00–013*, US Environ. Prot. Agency, Bethesda, MD
91. US Environ. Prot. Agency, Off. Water. 1999. Regulatory impact analysis and revised health risk reduction and cost analysis for radon in drinking water. *Rep. EPA-815-D-99–002*, Washington, DC
92. Carson RT, Mitchell RC. 1993. The value of clean water: the public's willingness to pay for boatable, fishable, and swimmable quality water. *Water Resour. Res.* 29:2445–54
93. Lyon RM, Farrow S. 1995. An economic analysis of Clean Water Act issues. *Water Resour. Res.* 31:213–23
94. Leggett CG, Bockstael NE. 2000. Evidence of the effects of water quality on residential land prices. *J. Environ. Econ. Manag.* 39:121–44
95. Morgan C, Owens N. 2001. Benefits of water quality policies: the Chesapeake Bay. *Ecol. Econ.* 39:271–84
96. Bockstael NE, Hanemann WM, Kling CL. 1987. Estimating the value of water quality improvements in a recreational demand framework. *Water Resour. Res.* 23:951–60
97. Massey DM, Newbold SC, Gentner B. 2006. Valuing water quality changes using a bioeconomic model of a coastal recreational fishery. *J. Environ. Econ. Manag.* 52:482–500
98. Montgomery M, Needelman M. 1997. The welfare effects of toxic contamination in freshwater fish. *Land Econ.* 73:211–23
99. Day B, Mourato S. 2002. Valuing river water quality in China. In *Valuing the Environment in Developing Countries: Case Studies*, ed. D Pearce, C Pearce, C Palmer, 3:25–66. Cheltenham, UK: Elgar

100. Choe K, Whittington D, Lauria DT. 1996. The economic benefits of surface water quality improvements in developing countries: a case study of Davao, Philippines. *Land Econ.* 72:519–37
101. Hamilton JT, Viscusi WK. 1999. How costly is clean? An analysis of the benefits and costs of Superfund site remediations. *J. Policy Anal. Manag.* 18:2–27
102. Gayer T, Hamilton JT, Viscusi WK. 2000. Private values of risk tradeoffs at Superfund sites: housing market evidence on learning about risk. *Rev. Econ. Stat.* 82:439–51
103. Kohlhase JE. 1991. The impact of toxic waste sites on housing values. *J. Urban Econ.* 30:1–26
104. Kiel KA. 1995. Measuring the impact of the discovery and cleaning of identified hazardous waste sites on house values. *Land Econ.* 71:428–35
105. McCluskey JJ, Rausser GC. 2003. Hazardous waste sites and housing appreciation rates. *J. Environ. Econ. Manag.* 45:166–76
106. Michaels RG, Smith VK. 1990. Market segmentation and valuing amenities with hedonic models: the case of hazardous waste sites. *J. Urban Econ.* 28:223–42
107. Ihlanfeldt KR, Taylor LO. 2004. Externality effects of small-scale hazardous waste sites: evidence from urban commercial property markets. *J. Environ. Econ. Manag.* 47:117–39
108. Greenstone M, Gallagher J. 2008. *Does hazardous waste matter? Evidence from the housing market and the Superfund program*. MIT Dep. Econ. Work. Pap. 05–27. Cambridge, MA
109. Kiel KA, Williams M. 2007. The impact of Superfund sites on local property values: Are all sites the same? *J. Urban Econ.* 61:170–192
110. Freeman AM III. 1991. Valuing environmental resources under alternative management regimes. *Ecol. Econ.* 3:247–56
111. Natl. Res. Counc. 2005. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. Washington, DC: Natl. Acad.
112. Polasky S. 2008. What's nature done for you lately: measuring the value of ecosystem services. *Choices* 23:42–46
113. Nelson E, Polasky S, Lewis DJ, Plantinga AJ, Lonsdorf E, et al. 2008. Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *Proc. Natl. Acad. Sci. USA* 105:9471–76
114. Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, et al. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front. Ecol. Environ.* 7:4–11
115. Polasky S, Nelson E, Camm J, Csuti B, Fackler P, et al. 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biol. Conserv.* 141:1505–24
116. Olmstead SM, Hanemann WM, Stavins RN. 2007. Water demand under alternative price structures. *J. Environ. Econ. Manag.* 54:181–98
117. Scheierling SM, Loomis JB, Young RA. 2006. Irrigation water demand: a meta-analysis of price elasticities. *Water Resour. Res.* 42:W01411
118. Renzetti S. 2002. *The Economics of Water Demands*. London: Kluwer Acad.
119. Colby BG. 1989. Estimating the value of water in alternative uses. *Nat. Resour. J.* 29:511–27
120. Daubert J, Young R. 1979. Economic Benefits from Instream Flow in a Colorado Mountain Stream. *Colo. Water Resour. Res. Inst. Completion Rep. 91*, Colo. State Univ., Fort Collins, CO
121. Whitehead JC. 2006. A comparison of contingent valuation method and random utility model estimates of the value of avoiding reductions in king mackerel bag limits. *Appl. Econ.* 38:1725–35
122. Loomis J. 1987. The economic value of instream flow: methodology and benefit estimates for optimum flows. *J. Environ. Manag.* 24:169–79
123. Brander LM, Florax RJGM, Vermaat JE. 2006. The empirics of wetland valuation: a comprehensive summary and a meta-analysis of the literature. *Environ. Resour. Econ.* 33:223–50
124. Barbier EB. 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. *Ecol. Econ.* 35:47–61
125. Acharya G. 2000. Approaches to valuing the hidden hydrological services of wetland ecosystems. *Ecol. Econ.* 35:63–74
126. Breaux A, Farber S, Day J. 1995. Using natural coastal wetlands systems for wastewater treatment: an economic benefit analysis. *J. Environ. Manag.* 44:285–91

127. Creel M, Loomis J. 1992. Recreation value of water to wetlands in the San Joaquin Valley: linked multinomial logit and count data trip frequency models. *Water Resour. Res.* 28:2597–606
128. Cooper J, Loomis J. 1993. Testing whether waterfowl hunting benefits increase with greater water deliveries to wetlands. *Environ. Resour. Econ.* 3:545–61
129. Bell FW. 1997. The economic valuation of saltwater marsh supporting marine recreational fishing in the southeastern United States. *Ecol. Econ.* 21:243–54
130. Mahan BL, Polasky S, Adams RM. 2000. Valuing urban wetlands: a property price approach. *Land Econ.* 76:100–13
131. Croitoru L. 2007. Valuing the nontimber forest products in the Mediterranean region. *Ecol. Econ.* 63:768–75
132. Starbuck CM, Alexander SJ, Berrens RP, Bohara AK. 2004. Valuing special forest products harvesting: a two-step travel cost recreation demand analysis. *J. For. Econ.* 10:37–53
133. Garrod G, Willis K. 1992. The amenity value of woodland in Great Britain: a comparison of estimates. *Environ. Resour. Econ.* 2:415–34
134. Pattanayak SK, Kramer RA. 2001. Worth of watersheds: a producer surplus approach for valuing drought mitigation in eastern Indonesia. *Environ. Dev. Econ.* 6:123–46
135. Ricketts TH, Daily GC, Ehrlich PR, Michener CD. 2004. Economic value of tropical forest to coffee production. *Proc. Natl. Acad. Sci. USA* 101:12579–82
136. Sohngen B, Mendelsohn R. 2003. An optimal control model of forest carbon sequestration. *Am. J. Agric. Econ.* 85:448–57
137. Kramer RA, Mercer DE. 1997. Valuing a global environmental good: U.S. residents' willingness to pay to protect tropical rain forests. *Land Econ.* 73:196–210
138. Adams C, Seroa da Motta R, Ortiz RA, Reid J, Aznar CE, de Almeida Sinisgalli PA. 2008. The use of contingent valuation for evaluating protected areas in the developing world. *Ecol. Econ.* 66:359–70
139. Loomis J, Larson D. 1994. Total economic values of increasing gray whale populations: results from a contingent valuation survey of visitors and households. *Mar. Resour. Econ.* 9:275–86
140. Simpson RD, Sedjo RA, Reid JW. 1996. Valuing biodiversity for use in pharmaceutical research. *J. Polit. Econ.* 104:163–85
141. Loomis JB, White DS. 1996. Economic benefits of rare and endangered species: summary and meta-analysis. *Ecol. Econ.* 18:197–206
142. Rubin J, Helfand G, Loomis J. 1991. A benefit-cost analysis of the northern spotted owl. *J. Forestry* 89:25–30
143. Kontoleon A, Swanson T. 2003. The willingness to pay for property rights for the giant panda: Can a charismatic species be an instrument for nature conservation? *Land Econ.* 79:483–99
144. Bowker JM, Stoll JR. 1988. Use of dichotomous choice nonmarket methods to value the whooping crane resource. *Am. J. Agric. Econ.* 70:372–81
145. Brown GM, Shogren JF. 1998. Economics of the endangered species act. *J. Econ. Perspect.* 12:3–20
146. Stanley DL. 2005. Local perception of public goods: recent assessments of willingness-to-pay for endangered species. *Contemp. Econ. Policy* 23:165–79
147. van der Heide CM, van den Bergh JCJM, van Ierland EC, Nunes P. 2008. Economic valuation of habitat defragmentation: a study of the Veluwe, the Netherlands. *Ecol. Econ.* 67:205–16
148. Christie M, Hanley N, Warren J, Murphy K, Wright R, Hyde T. 2006. Valuing the diversity of biodiversity. *Ecol. Econ.* 58:304–17
149. Adamowicz WL. 2004. What's it worth? An examination of historical trends and future directions in environmental valuation. *Aust. J. Agric. Resour. Econ.* 48:419–43
150. Mendelsohn R, Neumann J, eds. 1999. *The Impact of Climate Change on the United States Economy*. Cambridge, UK: Cambridge Univ. Press
151. Tietenberg T, Folmer H, eds. 2002. *The International Yearbook of Environmental and Resource Economics 2002/2003*. Cheltenham, UK: Elgar
152. Morgenstern RD. 1997. *Economic Analyses at EPA: Assessing Regulatory Impact*. Washington, DC: Resour. Future

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