6. "The difficulties of estimating global non-market damages from climate change"

Joel B. Smith, Jeffrey K. Lazo and Brian Hurd

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6. The difficulties of estimating global non-market damages from climate change

Joel B. Smith, Jeffrey K. Lazo and Brian Hurd*

1 INTRODUCTION

The potential non-market damages[1] from climate change are a strong motivation for control of greenhouse gas emissions. The term 'non-market' damages applies to impacts to sectors that do not have goods and services traded in the marketplace. The potential for disruption of ecosystems, loss of endangered species, harm to human health, and other non-market effects have been cited by many as sufficient reason to limit the extent of climate change. As noted in Edmonds and Sands (Chapter 7), the costs of limiting greenhouse gas emissions to substantially reduce global warming are not trivial. The tradeoffs between investing in reductions of greenhouse gas emissions versus absorbing market and non-market damages will be substantial.

An additional consideration is that should climate change be less than about 2 to 3°C, the net global market impacts may be less than a few percent of world product (Smith et al., Chapter 6; Mendelsohn, Chapter 5).[2] Given the limited total market damages, it is critical to determine the extent and value of non-market damages. A fundamental question is whether non-market damages so extensive as to justify controlling greenhouse gas emissions is enough to limit warming to a few degrees or less?

This raises some interesting questions about the extent and value of non-market damages from climate change:

- How well have we understood and quantified non-market climate-change impacts?
- Can the value of non-market impacts be credibly determined?
- Are non-market impacts similar across the globe or do they differ by latitude (for example, do higher latitudes have non-market benefits while lower latitudes have non-market damages)?

- Is it appropriate to monetize global non-market impacts of climate change?

These questions will be addressed in this chapter. We briefly review the literature on non-market impacts, particularly, impacts on ecosystems and human health. We then review methods for valuing non-market impacts. Most of this chapter is devoted to reviewing studies in the literature estimating the monetary value of non-market impacts from climate change. We address different approaches for estimating the value of non-market impacts including expert judgment, willingness-to-pay surveys, and site-specific analyses. We also review studies that estimate the monetary damages from impacts to human health, recreation, tourism, amenity values, and catastrophic impacts.[3]

2 A BRIEF REVIEW OF NON-MARKET IMPACTS

Space does not permit an adequate summary of the extensive literature on how climate change could affect non-market sectors. Readers are encouraged to consult IPCC (2001) for the Intergovernmental Panel on Climate Change's summary of impacts. Here, we briefly review what may happen to ecosystems and human health.

Ecological Impacts Could be Very Significant

Climate change is very likely to have substantial impacts on global ecosystems. We expect a general movement of ecosystems and species towards the poles (that is, to the north in the Northern Hemisphere) and to higher elevations because of higher global temperatures. This could result in the reduction or loss of some ecosystems and the expansion of others. The rate of climate change, for example, how quickly temperatures warm, is a very important factor affecting ecosystems. A more gradual transition may allow many more species to survive and the transitions may be less catastrophic. A more rapid change is likely to be more destructive.

The combination of climate change and human development is likely to result in significant loss of biodiversity and these losses are likely to be experienced across the world (for example, NAST 2000). Many ecosystems and species are already under stress from development and pollution. These stresses, unless relieved, will be exacerbated by climate change. The combination of other stresses and climate change will result in reduction of populations or loss of many individual species as well as substantial reduction or loss of some ecosystems (for example, mountain tundra, Cape Floral

Kingdom in South Africa; IPCC, 2001). It is not clear what the marginal effect of climate change is, but it is expected to be a contributing factor to adverse ecological impacts.

Human Health Impacts Are Generally Complex and Uncertain

The effects of climate change on humans appears to be more uncertain because of uncertainties about future societies' capacity to cope with climate change. In addition, there is the complexity of having not only adverse effects in some regions, but positive effects in others.

The risk of vector-borne diseases, such as malaria, will probably increase because of warmer (and wetter) conditions (for example, McMichael and Githeko, 2001). That is, more areas will become suitable for the spread of vector-borne diseases. Whether or not the number of cases increases and by how much is difficult to predict and depends on many factors (for example, Balbus and Wilson, 2000). A strong public health system should be sufficient to minimize the risk and contain any outbreaks. Indeed, increased levels of development could reduce the risk of climate change increasing the spread of vector-borne disease, although it would probably not eliminate it (Tol and Dowlatabadi, in press.) Thus, the risk of increased vector-borne disease is greatest for developing countries.

Mortality from heat stress could increase, particularly among the elderly and in inner cities. Estimates are for several hundred additional deaths per year in the United States (for example, Kalkstein and Greene, 1997). The number of cases of heat stress in developing countries would probably be much greater than the number of cases in developed countries. However, increased penetration of air-conditioning and other preventive measures could reduce heat-stress mortality (Chestnut et al., 1998).

Mortality related to low temperatures could drop, particularly in mid- and high-latitude countries. In some countries the reduction in winter mortality could be greater than the increase in summer mortality (for example, Martens, 1998). There is much uncertainty about changes in winter mortality, particularly because behavior is an important factor affecting it.

Today, most of the world's population lives in the tropics, where they are more likely to face increased risk of death from vector-borne disease and heat-stress mortality. Furthermore, the percentage of global population in the tropics will increase (United Nations, 1999). The percentage of the world's population living in high-latitude areas that may have reduced mortality will become smaller over time. If we also factor in the lower quality of health care in most low-latitude countries, it appears more likely than not that climate change will increase global mortality.

Quantifying Non-market Impacts of Climate Change

The discussion above presents many qualitative statements about impacts. In general, the literature indicates that climate change will have adverse effects on ecosystems and human health. There are few credible quantitative estimates of impacts, but there are exceptions. For example, Martens et al. (1999) estimate that under climate change, 100 to 300 million more people will be at risk of contracting malaria by 2100. Such estimates are scenario dependent and can be substantially changed by different assumptions about development and adaptation (for example, see Tol and Dowlatabadi, in press). There appear to be no credible estimates of how many endangered or threatened species would become extinct or how many ecosystems would be disrupted (although some studies have tried to identify ecosystems at substantial risk from climate change, for example, Malcolm and Markham, 2000). Thus, based on a review of the literature, it does not appear possible to reliably quantify nonmarket impacts of climate change.

3 VALUING NON-MARKET IMPACTS

The following is a brief discussion of the complex topic of valuing non-market impacts of climate change.

The prices of commodities can be used as an indication of the relative value of those commodities to society. This is true for market goods because prices reflect the aggregation of individual preferences that are implicit in the concepts of demand and supply. Behind the concepts of demand and supply and the price they yield are the economic notions of willingness to pay (demand) and willingness to accept (supply), both of which are commonly measured in monetary terms. Both willingness to pay and willingness to accept reflect the assignment of value by individuals. As Brown (1984) insightfully describes, assigning value is the end result of a process in which the individual applies a preference relationship to his or her set of 'held values'.

A taxonomy of held values includes personal values (for example, happiness, wisdom), professional values (for example, dedication, hard work), national values (for example, loyalty, patriotism), or issues such as the environment (for example, beauty, uniqueness). Such held values are not directly observable or measurable, but are key, along with the individual's experience and social context, in determining relative preferences and assigned value. Assigned values for market goods are routinely observed because they emerge as market prices. It is much more difficult to observe assigned values for non-market goods and thus, prices. Even notions of willingness to pay and willingness to accept can be inadequate proxies for describing and relating the underlying held values of a society or culture.

What Are Non-market Values?

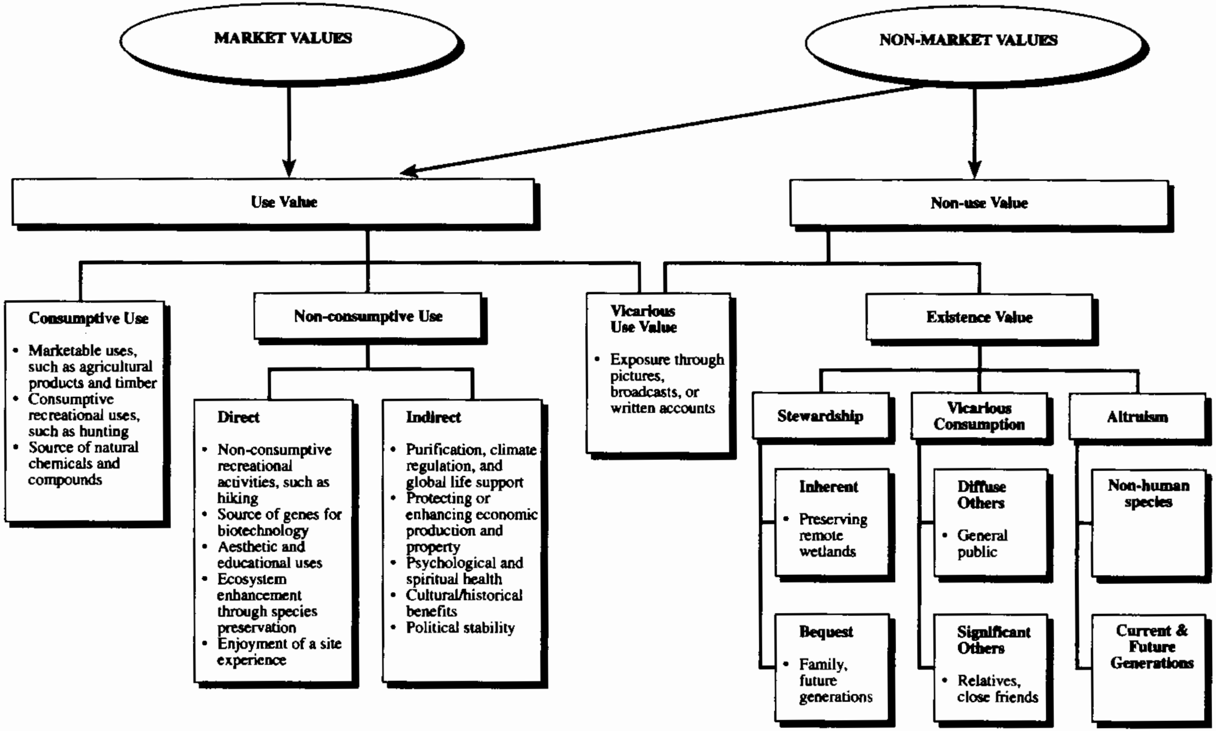
Environmental commodities generate services, which often are not valued (that is, bought and sold and priced) in regular economic markets. A significant concern of environmental economists has been to understand and explain these values. Figure 6.1 from Reiner and Sussman (1994) presents one of many possible taxonomies used to characterize such values. Defining non-market values can be controversial. A commonly accepted approach of defining different types of value is to refer to active-use and passive-use values. These are roughly equivalent to the use and non-use values illustrated by Reiner and Sussman.

Any attempt to define and measure different types of values must recognize that different individuals have different 'ethical structures' underlying their preferences toward environmental commodities. Does the ethical system underlying these values matter? Economists work within the paradigm of 'utility' (that is, satisfaction or well-being) and 'individual welfare'. The extent that an individual's utility is based on different ethical systems is not relevant. Whether a commodity or a service generates utility is all that matters. This becomes inherently difficult, though, when an ethical system does not 'permit' tradeoffs to occur, because tradeoffs are the basis for economists' approach to understanding and measuring values.

Valuation Methods

Several authors discuss the theory and methods of non-market valuation (Mitchell and Carson, 1989; Freeman, 1993; Garrod and Willis, 1999), and we do not attempt to provide a thorough review of this topic. Two general types of non-market valuation approaches are used by economists: revealed preference and stated preference. The primary issue is that different methods capture different values presented in Figure 6.1. Revealed preference methods rely on actual (observed or revealed) choices individuals make in order to infer the value of environmental commodities. Revealed preference methods are thus useful to measure some types of use values presented in the figure.

Revealed preference methods include travel cost, hedonic wage and hedonic property values, and averting behavior approaches. Briefly, the hedonic price approach assumes that the value of a market commodity implicitly reflects the value of all of the services that constitute that commodity, including non-market characteristics. The price of a house thus reflects, in part, the value of environmental amenities, such as the view and where that house is located.



Source: Reiner, D.M. and F.G. Sussman (1994), Perceptions of Ecosystem Damages and Economic Prescriptions, ICF Incorporated, paper presented at the Western Economic Association meeting, 29 June–3 July.

Figure 6.1 A taxonomy of economic values for ecological systems

Similarly, the hedonic wage approach assumes that comparing two identical jobs, one with a low risk of death and one with a high risk of death, the extra wage that has to be paid to the 'high death risk' employee (divided by the risk differential) is an indication of the value of death or injury on the job.

The travel cost approach is based on the economic assumption that if prices are lower, people will consume more of a good. For travel to a site that provides ecological services, if trip costs are lower, people will take more trips to that site. Trip costs include the time and travel expenses that people expend to visit a site. By calculating the number of trips to the site as a function of these trip costs, a demand curve can be derived. Averting behavior is based on the assumption that the amount of money someone is willing to spend to prevent or avoid a negative environmental impact is an indication of the damage from that impact. For instance the amount someone spends on in-house microbial water filters is an indication of how much it is worth to them to avoid illnesses from water-borne microbes.

Alternatively, stated preference methods (for example, contingent valuation method, conjoint choice) can be used to capture both use and non-use values, and are the only approach for capturing non-use values.[4] Stated preference methods generally survey individuals, asking them to express their preference over potential changes in non-market goods described to them in the survey. The term 'stated preference' encompasses all survey-based research in which people are asked questions about their preferences with the intent of estimating values for goods or services by analyzing what people say (that is, state). This is in contrast to studies that analyze what people do (that is, reveal).

Stated preference methods are often split into (i) direct valuation questions and (ii) stated choice questions. Direct valuation questions include questions such as 'How much would you be willing to pay for ...?'. These are often referred to as contingent valuation method questions. Choice questions include yes–no questions such as 'Would you be willing to pay $X for ...?' and questions where an individual chooses between alternatives with multiple attributes. The latter are sometimes called conjoint analyses, a term taken from the market research literature where this approach originated.

The total value of a commodity comprises active-use and passive-use values. For some use values, markets exist, for example, private hunting reserves, whereas for other use values, no markets exist, for example, the value of a scenic drive. For non-use values, by their nature, markets cannot and do not exist, for individuals cannot be charged a price for something from which they cannot be excluded, for example, simply knowing that blue whales exist. Market valuation methods (for example, market prices) thus can capture only some use values and no non-use values. Therefore, stated preference methods, both direct valuation and stated choice approaches, are important in that they are the only methods available to measure non-use values. By definition, non-use values do not leave a behavioral trail and thus revealed preference methods cannot be used to derive non-use values. Of additional importance is that stated preference methods can present scenarios of change that are beyond those currently experienced by individuals. Stated preference methods thus may be useful for considering the impacts of climate change that are beyond individuals' current experiences. However, non-use values identified through stated preference methods cannot be verified through observation of behavior.

A further problem with valuing non-market impacts of climate change has to do with when the impacts will be realized. Whatever method is used to value environmental and health changes, it can only measure the values of current generations. Revealed preference methods in general measure current generations' values for current conditions. However, the non-market impacts of climate change may well be greatest for generations yet to be born or too young to state or reveal a preference. Applying revealed preference values for climate-change impacts requires assuming that utility functions do not change over time. Stated preference methods can be used to value current generations' values for future conditions by presenting the valuation scenario as future conditions. Stated preference methods can thus be used to elicit current generations' values to prevent future changes. Alternatively, stated preference methods can be used to elicit current generations' values for changes in current conditions and then assume that these can be applied to future generations' values for future changes. In any event, stated preference methods cannot determine future generations' values for future changes without making the same assumption that revealed preference requires: that preferences do not change over time.

Benefits Transfer

Most approaches that attempt to derive aggregate values involve some sort of benefits transfer – that is, the application of values measured in one setting for one group to another setting for another group. Any valuation of future impacts on future individuals also involves a benefits transfer. A key assumption underlying such a transfer is that the utility function of future individuals in one place is reasonably equivalent to the utility function of similar individuals who may be in another place. To be sure, values between generations can change substantially. For example, past generations talked about 'swamps' as having low values, while we now talk about the importance of 'wetlands'. However, lacking any information on how future values may change, benefits transfer appears to be the best approach available. Another key aspect of such a transfer is that the choices of current individuals are based on the currently available choice set. The choice sets that future individuals will face will most likely be significantly different. These differences will occur because of the choices we make now, because of the impacts of climate change between now and the future, and because of new choices made available to future generations by both technological progress and the depletion of current resources.

Estimating the Value of Natural Ecosystems

One rather controversial topic that some economists have dared to tackle is the value of all ecosystems. We briefly review this literature not to derive such a number, because we think it lacks credibility and usefulness (we do not foresee a situation in which we shall consider losing or saving all of the world's ecosystems), but to demonstrate the difficulty of arriving at such a number. Natural resource economics tends to focus on deriving the value of ecosystems on the margin. For example, there are many studies estimating the value of few acres of wetland. It is not unreasonable to try to trade off the value of a marginal acre of wetlands versus a market good, such as housing. This is far different from trying to derive the value of *all* wetlands. Indeed, climate change poses the risk of losing or substantially damaging entire ecosystems.

While we are uncertain about climate-change impacts on natural ecosystems and how to value them, we have knowledge of the services that ecosystems provide. Several authors have developed or reviewed taxonomies of ecosystem services, including Christensen and Franklin (1997), Costanza et al. (1997), and Daily (1997). Some authors develop taxonomies for specific ecosystem types; for example, Whigham (1997) identified a wide range of services provided by wetlands other than commercial or recreational fishing. In Daily (1997), several contributing authors discussed functions and services of ecosystems that should be considered when evaluating the importance of ecosystems to society.[5] While not all of these services are discussed in terms of economic value, all are offered as important functions that society depends on in some manner. A partial compilation of these services as discussed in Daily (1997) includes:

- sequestration of materials and gases (including methane, carbon, and nitrogen or nitrous oxides);
- genetic material and maintenance of a genetic library;
- amelioration of weather and climate regulation;
- pest control;
- insect pollination;
- fisheries;

- soil retention, formation and maintenance of fertility;
- flood control and regulation of hydrologic cycles;
- cycling of matter;
- cultural values;
- building materials;
- food and fiber;
- fuel (biomass);
- waste assimilation and detoxification;
- recreation – including hunting and fishing;
- surface albedo;
- medicines and pharmaceuticals; and
- industrial use of bioproducts such as oils and pigments.

Drawing on Brown's concepts of valuing resources, Alexander et al. (1998) investigated several approaches to valuing global ecosystem services. The authors view the ecosystem as a productive economic input that supports the global economy. Their research seeks to identify the 'maximum amount that could feasibly be paid for these [ecosystem] services'. The scenario they pose is that of a discriminating monopolist who owns all ecological services in the global economy, and they ask, 'How much could this monopolist charge humans for using these services?'. At the upper extreme is the value of the world's output less the amount required for subsistence; in 1987, the authors estimated this value to be $16.2 trillion (88 per cent of world GDP, in 1987 US dollars).[6]

Alexander's approach, as with other attempts to value the globe's ecosystems, such as Costanza et al. (1997), seems rather narrow and reductionist. In the case of Alexander et al. (1998), their recognition that society's *willingness to pay* is fundamentally constrained by its *ability to pay* is compelling, but it rests on assumptions that ecosystems and their services are valuable *only* in as much as they contribute to societies' capacity to generate economic activity. Certainly without clear air and clean water our capacity to do work is diminished. However, the value of clean air and water is not simply that it better enables the labor force to produce, but that utility is enhanced directly – not only because income is greater but also because clean air and water enhance the value of all of our activities and enjoyments. Having good health, knowing that wildlife and ecosystems are not damaged, and enjoying the experience of not breathing and drinking fouled air and water provide, arguably, as much or more value than income from our labor. The estimates of Alexander et al. ignore the possibility that ecosystems are part of an endowment, and that perhaps implicit in that there is a right to the enjoyment of the resource that is independent of a capacity to pay for it.[7]

4 ESTIMATED DAMAGES FROM CLIMATE CHANGE

This section of the chapter reviews estimated non-market damages to natural ecosystems, human health, tourism and recreation, and amenity values. This is not a comprehensive assessment of the literature; instead, some interesting studies from the recent literature that are typical of the kind of research being conducted are reviewed and used to evaluate the state of the literature in estimating climate-change damages.

Estimates of Value of Natural Ecosystem Impacts

The estimates of the value of natural ecosystems impacts based on a few published studies are reviewed. Readers should bear in mind Tol's (1998, p. 7) warning about valuing such impacts: 'Climate economists therefore face a double problem, i.e., how to derive a total value of something which is unknown in quantity and price'. Examples of three approaches that have been used are given: using expert judgment to estimate damages, determining willingness to pay to avoid damages, and estimating site-specific damages using benefits transfer.

Expert judgment on global damages

Nordhaus and Boyer (2000) used the RICE-98 model to estimate global values of market and non-market impacts of climate change. Their basic approach, for both market and non-market sectors, was to measure *willingness to pay* (WTP) to prevent future change. This approach is akin to estimating the 'insurance premium' that different societies are willing to pay to prevent climate change and its associated impacts. That is, for each sector and region, they developed an estimate of WTP to avoid a 2.5°C increase in global mean temperature as a share of each region's GDP at a given point in time (usually a current time period), and then project future values by scaling with an adjustment factor based on future and current per capita GDP and income elasticity.

Nordhaus and Boyer assumed that the capital value of human settlements and ecosystems, which varies by region, ranges from 5 to 25 per cent of GDP (for example, for the United States this is estimated at 10 percent of GDP or about $500 billion in 1990 GDP levels[8]). They further assumed that each region has an 'annual WTP of 1 percent of the value of the vulnerable system (which is one-fifth of the annualized value at a discount rate on goods of 6 percent per year) to prevent climate disruption associated with a 2.5°C rise in mean temperature' (p. 86). On a global basis, Nordhaus and Boyer estimated that settlement and ecosystem damage represents about 9.5 percent of all damages (including extreme events). For the United States, they estimated the damages of 2.5°C warming on ecosystems at 0.10 percent of GDP.

Table 6.1 Estimated natural ecosystem damages for 1 °C increase in global mean temperature

Region	Monetary damages (US$ billion)
US & Canada	15
Western Europe	19
Pacific OECD	8
Eastern Europe/Former USSR	12
Middle East	2
Latin America	4
South/SE Asia	5
China	2
Africa	2
Total	69

Source: Based on Tol (1998, Table 3).

Another example of expert judgment is Tol (1998), who calculated a combined WTP to avoid damages to natural ecosystems. He stated that his estimated damages capture use, option, and existence values. He assumed a WTP of $50 per person per habitat and that one habitat per year is lost. He adjusted the WTP for GDP/capita and assumed a positive income elasticity for WTP. The results are displayed in Table 6.1. Tol's estimate of global WTP to avoid ecosystem damages is about 0.2 percent of current global GDP.

One interesting outcome of such studies is whether total non-market damages exceed total market damages. Nordhaus and Boyer (2000) estimate that the non-market damages related to health, ecosystems, and settlements (0.27 percent of global product) nearly cancel the non-market amenity benefits related to improved recreation and leisure (0.29 percent of global product) at 2.5°C of global mean temperature increase. So, their estimate of net non-market damages is close to zero. On the other hand, Nordhaus and Boyer estimate that the absolute value of non-market impacts is 0.56 percent of global product, while the absolue value of market impact is 0.50 percent of global product. So, their estimate of the absolute value of the non-market impacts is quite close to their estimate of the absolute value of market impacts.[9]

Studies such as Nordhaus and Boyer (2000) and Tol (1998) have the advantage of providing specific monetary estimates of climate-change damages, but their limitation is that they are largely based on expert judgment. There are substantial uncertainties with these estimates and little indication of confidence limits. Thus, there is low confidence even in estimates of relative non-market versus market damages.

Willingness-to-pay surveys

In contrast to the global approach and expert judgment of Nordhaus and Boyer is Layton and Brown (undated; and 1998), who used a stated preference survey to elicit individuals' WTP to prevent ecosystem change due to climate change over 60- and 150-year intervals. The ecosystem change valued is a shift of forests to higher elevations along the Front Range of Colorado, with prairie ecosystems replacing the forests. Layton and Brown conclude that WTP to prevent a change occurring over 60 years is not statistically different from the same changes over 150 years: $20 a month for altitudinal shifts of 600 feet to $80 a month for 2500 feet. Layton and Brown's results are reasonably robust to various model specifications and modeling approaches and show that individuals are willing to pay significant amounts to prevent potential future changes in ecosystems in response to global climate change. As Layton and Brown state, 'Little research has attempted to value ecosystems in their entirety, and none to our knowledge along with global climate change' (p. 8). They also state that 'we are aware of no markets that reveal the preferences of those alive today to help others 150 years in the future' (p. 22).

Studies such as Layton and Brown (1998) have the advantage of being replicable. It would be interesting to conduct similar studies of WTP and see if results are consistent. The results of these studies are difficult to interpret because it is not clear if respondents are embedding larger concerns about climate change in their answers (Kahneman and Knetsch, 1992). As Layton and Brown state 'perhaps the greatest challenge is in disentangling the willingness to pay (WTP) to prevent forest loss, from WTP to prevent all the other expected impacts of global climate change' (p. 9). Respondents could be giving a WTP to avoid *all* impacts of climate change, not just the one they are asked to respond to. Thus, even if we knew the quantitative ecological impacts from climate change, it is not clear whether results such as this can be scaled up by different impacts and population to arrive at a credible national or global damage estimate.

Kinnell et al. (forthcoming) use a contingent valuation survey to elicit values from Pennsylvania duck hunters for reducing impacts on the Prairie Pothole Region from climate change and agricultural activities. The Prairie Pothole Region is a major breeding ground in central US and Canada for ducks that migrate through Pennsylvania. Mean annual WTP to prevent agricultural or climate-change impacts on the pothole region is about $11. The stated values for preserving Prairie Potholes were higher when the source of the impact was indicated as climate change as opposed to agricultural causes and was larger for larger potential impacts on the Prairie Pothole Region. An interesting aspect is that individuals indicate a WTP to prevent climate-change impacts on an ecosystem that is spatially distinct from themselves.

Kinnell et al. also note that the values stated by respondents could incorporate embedding for prevention of a broader array of ecosystem impacts rather than those just to the Prairie Pothole Region.

Site-specific analyses

A third approach is to examine site-specific ecosystem impacts and use benefits transfer to estimate damages. For example, the World Bank (2000) and Stratus Consulting (2000) found that climate change could significantly affect low-lying island nations, which are particularly vulnerable to changes in sea level. The coral reefs that surround many of these islands may be highly sensitive to warmer temperatures and increased CO_2 concentrations, both of which inhibit coral growth (for example, Kleypas et al., 1999).

Coral reefs support nearshore commercial, recreational, and subsistence fisheries, and other economically valuable marine species. They serve important functions as atoll island foundations, natural protective structures along the coast by dampening of waves, sources of beach sand, sources of aggregate for construction, and tourist attractions. Bleaching events, which kill reefs, are expected to be more frequent, leading to declines in reef fisheries and long-term coastal protection.

For Fiji, the damages from climate change are estimated to average between \$5 and \$14 million annually by 2050 (in 1998 US dollars). These values were derived by estimating impacts to key services such as fisheries, tourism, and coastal protection, and estimating their current values and sensitivity to climate changes. For example, to estimate the value of mangroves (that is, WTP) for providing valuable habitat to support both commercial and subsistence fishing, recreation, supply medicinal plants, habitat support for wildlife, and coastal protection, per hectare values were developed from a variety of economic studies and applied to the current stock of Fijian mangroves (about 23,500 ha). The values include the value of goods or services delivered through a market (for example, local fish bought and sold in the local market) and non-market context (for example, fish caught by subsistence anglers).

The authors of these studies note that their economic analyses are based on a series of assumptions, models, and professional judgment. The methods used are intended to produce conservative (that is, lower-bound) estimates. In particular, there are many omissions, biases, and uncertainties acknowledged by the authors, and most of these are believed to result in underestimates of the losses. Examples of values that may not be covered in these damage estimates include non-use values (for example, existence, bequest, option values), trade in aquarium species, infrastructure maintenance and repair costs, and biodiversity.

Studies such as those described here have the advantage of being very specific. A disadvantage in addressing global damages from climate change is the difficulty of replicating such studies in enough cases to have sufficient examples upon which to develop a credible global estimate. In addition, there are problems with benefits transfer. It is not clear that other cultures share what are essentially Western values. They may put less or more value on ecological systems such as coral reefs. Studies such as this are interesting, particularly for identifying relative damages, but it appears to be premature to use them to develop estimates of global damages.

Human Health

While there are relatively more reliable quantitative estimates of the loss of human life of natural systems impacts, and there are more established techniques for valuing human life than valuing ecosystem impacts, the topic of the value of human life has been particularly controversial.

The controversy over valuing human life exploded during review of the IPCC's Second Assessment Report, which included estimates of global willingness to pay to avoid risk to human life (Pearce et al., 1996). The controversy arose because some studies adjusted the value of a statistical life (VSL) based on per capita GDP. This can lead to the conclusion that there is a higher WTP to avoid risk to people in wealthier countries than in poor countries.[10]

There is no right approach for valuing global health impacts. The prescriptive view, the 'moral imperative', treats all lives as equal and values them using the OECD (Organization for Economic Cooperation and Development) value of life for all lives under the polluter pays principle. However, this has a weak economic theoretic basis.

Assigning a single value to all lives based on the value estimates derived mainly from studies in developed countries results in a misallocation of resources in developing countries. VSL estimates are based in theory on individuals' attitudes toward risk and their willingness to pay to avoid risk – and this WTP is thus based on their actual income. Using an inflated value estimate for reductions in mortality will likely shift resources from other programs, which are valued in 'local' value terms. The VSL in a developing country is based on attitudes toward risk that cannot necessarily be transferred from developed countries, even if income levels can be scaled on per capita GDP measures.

In contrast, the descriptive view examines how much people are willing to pay to reduce risk to human life.[11] The human capital approach treats people as economic machines and values life according to the net value of produced output. The human capital approach is not the correct measure for policy analysis because it does not measure individuals' values as defined in welfare economics. Human capital does not capture individuals' attitudes toward risk and does not measure consumer surplus losses which are relevant in welfare analysis. Similarly, cost-of-illness approaches, which encompass more than just human capital, do not capture WTP measures and furthermore may be distorted because of social insurance programs.

The theoretical economic approach involves willingness to pay for reduced risk to human health or willingness to accept compensation for increased risk to human health. This requires a clear understanding of the hypothesized risk from climate change. Another problem is that it depends on other factors like the distribution of wealth; that is, the value of poor people's lives is constrained by their net income.

In the climate-change literature, different approaches have been used, from using a single average value (for example, Cline, 1992; Titus, 1992; and Fankhauser, 1995) to a varying approach that depends on regional per capita GDP (for example, Nordhaus and Boyer, 2000 and Tol, 1998).

For example, Nordhaus and Boyer (2000) relied on data from Murray and Lopez (1996) on the current prevalence of climate-related diseases (for example, malaria, dengue fever). These data are given for both the years of life lost (YLLs) and disability adjusted lives lost (DALYs). They use three approaches to estimate the effects of climate change: (i) assume that one-half (one quarter in sub-Saharan Africa) of the gains in health estimated by Murray and Lopez for 1990 to 2020 will be lost as a result of 2.5°C warming, (ii) adjust health impacts for each region to approximate changes in climate analogue regions, and (iii) apply a regression approach estimating the relationship between illness and mean regional climate. In all cases, life-years are valued as two years of per capita income. For the United States, Nordhaus estimates the health-related damages are approximately 2.7 percent of total damages (0.02 percent of GDP), or roughly $1.4 billion.

Our view is that if it is necessary to apply a VSL, it should be in a manner consistent with the level at which decisions are being made. If a decision is being made just for India, for example, on protection of human life versus other investments, then it is reasonable to use a VSL appropriate for the Indian economy and Indian values. Using a VSL from an OECD country might result in overinvestment for protection of human life compared to other investments such as education. For climate change, we can think of a single global decision maker. In this case a single value of human life across the globe is appropriate (so we do not inadvertently value lives in one country more than another). This single value could be based on global average GDP per capita.

Recreation

A few studies have attempted to derive monetary estimates of climate-change impacts on recreation.

Loomis and Crespi (1999) estimated across a range of activities that a warming of 2.5°C and a 7 percent increase in precipitation across the United States could generate net gains in recreation benefits of $2.5 billion (1992 dollars), because activities such as golf and fishing and other freshwater stream and lake uses increase much more than cold-weather recreation, such as skiing, declines.

Mendelsohn and Markowski (1999) similarly estimated that modest warming leads to a net increase in outdoor recreation benefits, as hunting, fishing, and boating gains in consumer surplus outweigh losses in camping, skiing, and wildlife viewing. The authors estimate the value of this impact to the United States to be between $1.7 and $6.3 billion (in 1991 dollars) for a 2.5°C increase in temperature and a 7 percent rise in precipitation.

Robinson and Godbey (1997) surveyed time use by Americans and report that less than 5 percent of non-market time is climate sensitive (about 2.2 hours out of 39.4 hours per week). A slight positive impact is estimated for amenity impacts such as gains in camping and golf at the expense of skiing and hockey. A 2.5°C warming leads to an amenity increase of 0.3 percent of US GDP (the value reaches a maximum at about 20°C mean temperature, after which it declines). They applied this relationship to other regions (extrapolating from the United States) and find positive impacts for temperate and cold high-latitude regions and negative for warm regions (that is, those with monthly mean temperatures above 20°C).

Nordhaus and Boyer (2000) estimated slight increases in global welfare associated with changes in climate-sensitive recreation (about 0.28 percent of US annual GDP, $19 billion in 1995 baseline).

Tourism

A few studies have attempted to estimate economic impacts of changes in tourism. For example, Maddison (forthcoming) developed a pooled travel cost model to look at the impact of climate variables (temperature and precipitation) on choice of vacation site for British tourists using aggregated country data to estimate change in the number of trips to a site (87 countries) as a non-linear function of temperature. Using this model, Maddison identified an optimal destination temperature and derived welfare estimates based on changes in temperature and precipitation under different scenarios. Using data from the United Kingdom Meteorological Office's (UKMO) general circulation model, which indicated a uniform increase of around 2°C for Southern Europe by 2030, Maddison valued impacts on tourism for Greece, Spain, and the Seychelles. As an example, Maddison shows that there would be a small increase in consumer surplus of just over £11.6 million ($16 million), and the flow of British tourists increases by 2.9 percent for Greece.

If the whole of the Seychelles were inundated, the total consumer surplus loss would be £2.2 million pounds per year (1995 values; $3 million).

Maddison's model deals only with use values (Maddison is very explicit on this point). Thus values for some low-lying island countries are found to be smaller even if they are totally inundated because they tend to be far away for British tourists and have lower visitation rates. It is noted, though, that there may be large passive use values (Maddison calls these 'existence' values) for these countries. The paper further recognizes that it does not deal with substitution among sites or changes in the total number of visits across all sites.

Others have examined the impact of climate change on tourism, but there has been little work on estimating the economic impacts of such changes (Smith, 1993; Schackleford and Olsson, 1995; Wall, 1998).

Amenity Values

A number of studies have attempted to estimate changes in amenity values. Amenity value is human centered and is largely related to time and leisure activities. On a global basis, Nordhaus and Boyer (2000) estimate amenity benefits from a 2.5°C warming of $19.4 billion. This result derives from surveys and analyses by the authors showing a rise in time allocated to outdoor recreation and leisure activities as temperatures rise. For example, Nordhaus and Boyer observe that the positive gains from activities such as hiking and camping outweigh the losses to activities such as skiing.

Case and Leary (1995) used a hedonic price model to test the hypothesis that climate amenity values are capitalized in housing rents and wages, and to estimate the implicit price of such amenity values. They find that mild climates are preferred (that is, cooler rather than hotter summers and warmer rather than colder winters). Their estimates for decreased prices of single family homes as a result of higher summer temperatures range from –$30 to –$160 (1990 dollars) per degree Fahrenheit increase. On the winter side, the authors find an average increase of $5 per degree in winter temperatures. They also find less cloud cover preferable to more cloud cover. Graves (1980, as cited by Leary, 1994) demonstrated that outmigration and inmigration patterns are influenced by temperatures and temperature variations. This result is not robust, since other studies suggest that the effect of climate is insignificant compared to the driving force of economic opportunity.

One of the more detailed amenity value studies was recently conducted by Maddison and Bigano (undated). Using housing, wage, climatic, and regional data, they developed a hedonic model of the impact of climate variables on net household income differentials as an indication of the amenity values of climate in Italy. The analysis controlled for the influence of coastal and alpine areas, the presence of metropolitan areas, population density, and latitude and longitude in addition to climate variables (temperature, precipitation, and percent of clear sky). Their analysis found significant disamenity values for both high July temperatures and January precipitation. Climate-change models predict increases in July temperatures and January precipitation, and the analysis suggests that there would be significant amenity welfare losses in Italy due to climate change. Maddison and Bigano calculated implicit prices for climate variables for five metropolitan areas but did not calculate projected welfare losses under climate change. Maddison and Bigano report implicit prices by city for amenity values of climate variable in thousands of Italian lira per household per year (undated, Table 4). These implicit prices indicate the welfare effects of marginal changes in the level of climate amenities. Converting to US dollars,[12] for a household in Milan, a 1°C increase in July temperature would lower welfare by $286 per year. Similarly, for a household in Milan, a 1 mm increase in precipitation in January would lower welfare by $19 a year, a 1 percent increase in clear skies in January would increase welfare by $140, and a 1 percent increase in clear skies in July would lead to a $274 per year increase in welfare. They note that such calculations would be upper bounds since the model does not allow for relocation due to changes in climate amenities.

It seems reasonable to conclude that lower latitudes, where temperatures are already relatively high, would most likely face a loss of amenity values whereas higher latitudes, where temperatures are relatively low, would most likely experience an increase in amenity values.

Catastrophic Impacts

There is very little published literature addressing the WTP to avoid catastrophic impacts of climate change such as break-up of the West Antarctic Ice Sheet or slowdown of the North Atlantic Thermohaline Circulation. However, Nordhaus and Boyer (2000) examined the issue of catastrophic loss and developed some stylized estimates using results from a 'survey' of experts, in which they were asked to assign probabilities to several climate and high-consequence events. The results led them to estimate WTP to avoid catastrophic losses in the United States associated with a 2.5°C warming to be 0.45 percent of GDP and 2.53 percent of GDP with a 6°C warming, where catastrophic loss is given as a 30 percent drop in income. Note that this estimate of willingness to pay to avoid catastrophe dwarfs estimates of willingness to pay to avoid damages in other impact categories. The literature contains virtually no information on the economic consequences of catastrophic impacts of climate change (that is, whether such impacts will lead to a 30 percent loss of GDP).

A Possible Approach

It appears to be almost fruitless to try to develop estimates of global WTP to avoid non-market damages from climate change – at least using the methods reviewed here. Another approach, however, is possible. This involves first monetizing what can credibly be quantified about benefits and costs of greenhouse gas emissions control. This would mainly involve effects of climate change on markets, where values of goods and services are much better established. The market benefits of controlling greenhouse gas emissions should be subtracted from the costs of emissions control.[13]

The net costs of control can be compared with qualitative or quantitative descriptions of non-market impacts of climate change. The non-market impacts can be expressed in terms that may be more meaningful to people than monetary value. The net number of people who may die can be quantified and ecosystem impacts can be quantified (for example, species loss) or described. People could then indicate their preference as to whether it is better to (i) invest in greenhouse gas emissions control or (ii) allow the impacts of climate change to happen. This could be done for different control levels, indicating the cost of reducing emissions to different levels and the consequences of the emissions in terms of non-market impacts.

This approach is similar to a referendum question used in stated preference valuation approaches. A key aspect of this approach would be clearly explaining the potential negative and positive impacts with and without a climate-change policy and the associated costs the individual would face. The individual would also have to understand the market impacts he or she would face and then state a preference over the potential non-market impacts and control costs.

The major limitation in applying such an approach is that we currently lack good information on non-market impacts. This is particularly true for ecosystem impacts. This suggests that more research to better understand and quantify ecosystem and other non-market impacts of climate change is needed.

5 FINAL THOUGHTS

Assessing economic damages from climate change to non-market systems, that is, ascribing monetary value, is, to say the least, a very difficult and challenging exercise. This chapter reviews a number of approaches, none of which appears to provide results that give us much confidence. The expert judgment approaches give comprehensive numbers but there is no information about the confidence limits of the results. The 'bottom-up' approaches, such as surveys or estimates of willingness to pay for specific impacts, cover such a small portion of the potential impact that they leave us wanting with regard to how these narrow results can be aggregated to a credible and meaningful global number.

Some interesting insight can be gained from the available literature on non-market damages. While the magnitude of these damage estimates may have little credibility, the sign of the impact is of interest and may hold up over time. The literature generally reports that there will be damages associated with ecosystem impacts. Even though some species could gain and there could be temporary increases in productivity (for example, Cramer et al., 2001), the literature on climate-change impacts consistently concludes that species and ecosystem diversity would be reduced by climate change. Thus, there appears to be little doubt that there will be net damages associated with ecosystem impacts.

The literature predominantly shows damages to human health, primarily based on estimated increases in mortality. However, as the IPCC Third Assessment (IPCC, 2001) points out, there may be mixed human health impacts in many countries. Given the large populations in tropical countries and their relatively poor health-care systems, it appears more probable that there will be increased rather than decreased global deaths from climate change.

In contrast, the studies on recreation impacts show a net positive effect. This is because the value of increased 'warm' weather activities appears to outweigh the value of decreased 'cold' weather activities. These studies have only limited geographical application (the United States) and need to be extended to more areas before global conclusions can be drawn.

Studies on amenity values and tourism appear to be more equivocal. Maddison and Bigano's study estimates reduction in amenity values, but only for one country. One would expect that higher-latitude countries may have increased amenity values, while lower-latitude countries may have decreased values. Studies on tourism indicate that tourist activities may shift location. This seems reasonable since people will continue to travel for vacation but may choose different destinations based on change in climate. There may be little net change, but there will certainly be winners and losers.

On the whole, it appears as if we are far away from being able to derive a credible and useful estimate of global non-monetary damages from climate change. However, readers should not assume that all attempts to estimate monetary value of non-market damages are fruitless. Indeed, while it is extremely difficult to credibly monetize *total global* non-market damages, quantifying non-market impacts of climate change and identifying services that can be lost, both of which are necessary in order to estimate non-market damages, will provide very useful information to policymakers on the consequences of climate change. In addition, we believe that credible regional or local estimates of the monetary value of many non-market impacts can be established. Such estimates can be very useful in understanding the relative values of non-market climate change impacts and how those values may change as climate change becomes more severe.

NOTES

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1. The term 'damages' is typically used to describe economic impacts from pollution. In the case of global warming, not all impacts are negative. Should there be net benefits, the sign of damages would be negative. However, as noted below, we expect that net impacts of climate change on natural ecosystems and human health will be negative.
2. As Mendelsohn notes, at such a level of warming, impacts to markets in developed countries in mid- and high latitudes may be positive, while the impacts to markets in developing countries in low latitudes may be negative. As Goulder (Chapter 4) notes, when equity is considered, the net market may be negative even at a few degrees of warming.
3. It should be noted that many of the studies we survey were not designed to arrive at global estimates of non-market damages. Many are more appropriate for estimating regional or local non-market damages from climate change.
4. Although there have been several critiques of the contingent valuation method (for example, Kahneman and Knetsch, 1992; Desvousges et al., 1993), others agree with EPA's statement that 'We believe that contingent valuation (CV) is a useful methodology, particularly for determining passive use damages that cannot be measured in any other way. The practical choice is between using CV or implicitly assigning a zero value to passive use damages. We believe that CV, when carefully done, can provide reliable results for determining damages at a reasonable cost' (USEPA, 1994, p. iii).
5. Some of the service flows mentioned by Daily and others are compiled from other authors and not discussed in depth here.
6. In 1997 dollars, Alexander et al.'s estimate would be $18.4 trillion, based on the chain-type price indexes for gross domestic product (CEA, 2000). As a percentage of current global product, the estimate would be about $35 trillion.
7. The difference between capacity to pay for ecosystems and willingness to pay to reduce risks to ecosystems is similar to the difference between cost-of-illness (COI) and value of statistical life (VSL) approaches to valuing morbidity risks. It is generally recognized that the COI approach is not necessarily the correct measure for policy analysis and that it may not directly measure welfare changes. VSL measures are also known to be related to, but not constrained by, income levels since they are based on willingness to pay to avoid the risk of death, not willingness to pay to avoid death. In a similar manner the appropriate measure of the value to prevent climate-change impacts to ecosystems is a risk-based measure and thus may not be constrained by income.
8. It would be about $100 billion based on current US GDP.
9. In addition, Nordhaus and Boyer assume that at 2.5°C of mean global temperature increase, there is a willingness to pay of 1 percent of global product to avoid catastrophes such as very high sea-level rise or the runaway greenhouse effect (see below). Such catastrophes would cause both market and non-market damages and the authors do not identify the relative share of such damages.
10. This conclusion can be verified through observation of such behavior as the difference in safety investments in wealthy and poor countries.

11. It is important to note that there is very little discussion of the potential morbidity impacts from climate change. There is also generally much less information on individuals' values for morbidity compared to estimates of mortality estimates. Another issue in using VSL estimates is that these are often based on wage risk studies for middle-aged working individuals. How to adjust VSL estimates for the young, elderly, or specific susceptible populations is unclear.
12. www.oanda.com/convert/classic June 20, 2001: 1,000 Italian lira = 0.44125 US dollars.
13. We recognize that there still remain substantial uncertainties and disagreement about the cost of greenhouse gas emissions control and the market impacts of climate change.

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