IIASA

International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Tel: +43 2236 807 • Fax: +43 2236 71313 • E-mail: info@iiasa.ac.at • Web: www.iiasa.ac.at

INTERIM REPORT IR-97-056/August

Economists and Ecologists: Different Frames of Reference for Global Climate Change

Anthony G. Patt (patt@iiasa.ac.at)

Approved by
Joanne Linnerooth Bayer (bayer@iiasa.ac.at)
Leader, *Risk, Modeling, and Policy*

Contents

Introduction 1
Theory 4
  Use of Cost-Benefit Analysis 4
  Risk Aversion and Utility Functions 5
  Discount Rates 10
  Cultural Theory 12
Application 13
  Using Economists' Assumptions 13
  Using Other Assumptions 15
  Interpreting the Model 16
Conclusion 18
Appendix—Mathematical Model of Climate Change 21
  Climate Change Equations 21
  Deriving Cost Parameters 23
  Additional Parameter Values 24

Abstract

Economists and ecologists, in general, have offered differing opinions about the seriousness of climate change and the need for rapid reductions in greenhouse gas emissions. Economists have tended to urge caution, focusing on the potential for large-scale cutbacks to upset the economy. Ecologists have tended to focus on the potential for catastrophic losses from climate change, and have urged extensive shifts in policy. This paper uses the tools of cost benefit analysis and the decision sciences to examine why members of the two disciplines often reach different conclusions. First, economists and ecologists start from different perspectives about what is the point of reference against which policies should be judged. Second, economists and ecologists tend to apply different discount rates to future impacts of climate change. Third, economists and ecologists are likely to interpret differently the substantive findings and expressed uncertainties of formal cost-benefit analysis. Using a simplified version of the DICE model of climate change, this paper explores how these different viewpoints can be expressed in practice.

Acknowledgments

I would like to acknowledge the many helpful comments on earlier drafts of this paper that I received from Joanne Linnerooth Bayer, Thomas Schelling, Michael Thompson, and Richard Zeckhauser. All remaining errors of fact and analysis are mine alone. I have written this paper while a participant in the 1997 Young Scientists Summer Program at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. Funding for my participation came from the United States National Science Foundation, and was administered by the American Academy of Arts and Sciences and IIASA.

About the Author

Anthony G. Patt is a doctoral student in Public Policy at the John F. Kennedy School of Government, Harvard University. He has also practiced as an environmental attorney in the United States, and consulted as a land-use planner. Currently, he is investigating different individual and social responses to risk and uncertainty, particular in matters dealing with environmental quality and global sustainability. In addition to the Risk, Modeling, and Policy Project at IIASA, he is a participant in the Global Environmental Assessment Project at IIASA and the Belfer Center for Science and International Affairs at Harvard University. His advisors are Professors William Clark and Edward Parson.

Economists and Ecologists: Different Frames of Reference for Global Climate Change

Anthony G. Patt

Introduction

In research on the environment, and climate change as an issue in particular, many traditional economists seem to be staid and complacent. Market transactions, they reason, allow people to pursue the objectives that they value most. People substitute different public and private goods, among them environmental and manufactured amenities. To the extent that the environment has and will be degraded, it is in the pursuit of causes that are worthwhile, such as economic growth and increased human happiness. In a well-known (among economists) bet between the economist Julian Simon, and the ecologist Paul Ehrlich, Simon bet that the prices of a variety of natural resources would decline over time as demand shifted to new technologies, while Ehrlich predicted increasing resource scarcity and thus rising prices. Simon, it turns out, won the bet on every count.

A contrary view sees markets and political forces as less benign. History is a series of resource exploitations, and unless we take action now the future will promise more of the same, although at a global scale. Ludwig et al. (1993, 17) point out four essential causes for repetitive exploitation: wealth, or the prospect of wealth, generates political and social power that is used to promote resource exploitation; environmental science is hampered by an inability to conduct controlled experiments, so that consensus occurs only after substantial environmental change has occurred; the complexity of environmental systems makes reductionist management principles of limited use, and favors management by trial and error; and, natural variability masks the initial effects of overexploitation. While past incidents of exploitation have ruined local fish stocks, or rendered agricultural areas infertile, current and future practices could influence human development worldwide.

For convenience, I call the two views the *economic* and the *ecological*. The typology needs to be taken with a grain of salt, however. First, it does not convey the breadth of analysis and opinion among practitioners in both fields. Certainly there are economists whose analysis recommends large and immediate policy action, just as there are ecologists who are less concerned about climate change. Second, it clumps analysts into just these two camps, and its clumping can be tautological. There are analysts from a great many natural and social science disciplines who are examining climate change. Whether we think of their analysis as primarily economic or ecological in orientation depends on exactly that which we are seeking to explain: the dominant assumptions that they are using. However, the typology is useful because it allows us to classify, and thus remember, general categories of arguments. In general, economists performing cost benefit analysis (CBA) have used a set of assumptions that drives their models in the direction I have noted. In general, ecologists have been more concerned with system instability.

Both approaches are internally consistent, yet often times mutually incompatible. Policy makers frequently justify their particular stances towards environmental regulation based on one or the other of these viewpoints. In the issue area of climate change, the use of these arguments is especially pronounced. During the Bush administration, for example, the United States took a decidedly "economic" approach, and resisted the call for binding commitments to reduce greenhouse gases. This echoed the recommendations of many economists, who take the issue seriously yet urge governments not to overreact (Nordhaus 1994a; Manne and Richels 1991; Peck and Teisberg 1995). European nations, by contrast, have often relied on the more ecological or engineering-based perspective. Perhaps because they have less of an attachment to free markets, have a greater history of social control of individual action, or have a greater historical familiarity with collective environmental management, European governments have tended to favor policies placing tighter limits on greenhouse gas emissions. Certainly the difference between European and United States responses can be attributed, in part, to causes other than this academic divide. The United States, lacking a parliamentary system, find it difficult to make sweeping policy changes. The European governments may have had other reasons for advocating binding targets: the Thatcher government in Britain was eager to break the coal union, and the Schmidt government in Germany wanted to maintain the high ground against the Green Party on the issue of nuclear energy. Still, the general political discourse in Europe has focused on the dangers of uncontrolled climate change, while in the United States the government has downplayed the risks of climate change compared to the burden on the economy of reducing carbon emissions.ˆ [1] For instance, in 1990 the Dutch government issued the following statement:

> [W]e think that a cost benefit analysis has limited applicability in guiding policy formulations especially when dealing with global intergenerational problems. This is not only due to our limited understanding of global geospheric / biospheric processes, but also due to our limited capability to predict the future. Besides, other considerations point to the need to take action now (White House Conference 1990).

At the same time, the United States government issued a statement highlighting the uncertainties inherent in the climate change problem, a desire to base policy on cost benefit analysis, and a rationale for waiting before implementing any new policies:

> The United States believes that the uncertainties associated with the timing and magnitude of possible global change mean that policies will vary in their appeal as uncertainties are reduced; an appropriate strategy to address possible global change based on today's knowledge and in light of today's economic environment may be wholly inappropriate within a decade (White House Conference 1990)

The divergence between these two perspectives can be both important and divisive. It is important because taking action to address climate change will require coordinated global resolve. Unless policy makers from different political cultural traditions can agree on certain fundamentals, it is unlikely that they will achieve progress. The difference is divisive because behind the two perspectives lie different sets of values and assumptions. Both perspectives make sense according to their own background beliefs; reconciling the two views requires not further analysis within each framework, but discussion of the values and assumptions themselves. At the recent Rio+5 meeting in New York, and again at negotiations in Bonn, American and European representatives had sharp differences of opinion, and little progress

---

[1] A notable exception is Vice-President Gore, who has been outspoken on the need for policies to address climate change and other environmental problems. At the same time, however, Gore has been less than influential in the deliberations of other American policy-makers.

towards emissions targets was made. In Bonn, for example, European ministers and environmental organizations accused the United States of blocking efforts to curb climate change, and the negotiations ended without agreement. The Conference of the Parties to the Framework Convention on Climate Change, planned for Kyoto in December of 1997, promises more of the same.

There have been a number of other attempts either to document or to explain the difference between the two perspectives. Economist William Nordhaus (1994b) identified the difference of opinion through analysis of a survey of nineteen experts on climate change, from different disciplines. On all counts, the natural scientists estimated the future impacts of climate change to be far worse than did the economists. The natural scientists, generally, focused on potential non-linear and catastrophic responses in geophysical and ecological systems to changes in greenhouse gas concentrations. The economists, generally, focused on the ability of people to adapt to changing conditions. While one group saw the potential for the spread of tropical diseases, the other saw the potential for farming in Siberia. Nordhaus does not, however, attempt to explain the reasons for the difference. By contrast, advocates of cultural theory, which I will discuss in greater detail later in this paper, attempt to explain the difference in terms of different conceptions of nature. They contend that social discourses can be classified into four general categories, and that the classification then explains and predicts the models and assumptions used within that discourse.ˆ According to cultural theory, the discourse of economists is consistent with an individualist worldview, while that of ecologists is consistent with an egalitarian worldview (Roe 1996).

Some economists are frustrated by the fact that many people do not agree with interpretations. As Lester Lave writes:

> Few people have addressed issues of global climate change within a benefit-cost framework, and few seem inclined to do so, even after the framework is brought to their attention. Not only do [economists] not control the debate, but the language and framework have been defined by people who see a balancing approach as unnatural, even wrongheaded, in thinking about these issues. If economists are going to engage a more general audience, [they] need to give more attention to the “world views” of the public and those who dominate the debate (Lave 1990, 98-9).

Lave offers three “world views” or mentalities: frontier, conservationist, and preservationist (Lave 1990).[2] Lave suggests that a CBA approach to climate change makes sense only to the conservationists; the frontier mentality sees no reason to worry about climate change; the preservationist mentality sees no justification for changing the climate to achieve greater economic growth.

In this paper, I attempt to explain the differences using an interdisciplinary set of tools. These include utility theory, prospect theory, mathematical explanations for discount rate discrepancies, theories of the sociology of scientific information, as well as a simplified version of Nordhaus’ DICE model of climate change. I believe that if the two perspectives are to be reconciled, then it is important to take the different analytic approaches seriously even as one attempts to explain their different results. Specifically, I seek to answer two questions. First, what values and assumptions lie behind the two analytical approaches, resulting in different intuitions about climate change? Second, how do those values and assumptions influence the use and interpretation of cost-benefit analysis (CBA)?[3]ˆ

---

[2] Lave’s world views are easily translated into cultural theory: with the frontier mentality is individualist; the conservationist is hierarchical; and the preservationist is egalitarian.

[3] These two questions raise a third issue, which I do not attempt to answer. That is, is my typology of approaches correct or helpful? I believe it is, but leave this question to further analysis.

Theory

Use of Cost-Benefit Analysis

Increasingly, decision-makers have come to rely on cost-benefit analysis (CBA) to examine policy options (Munasinghe et al. 1996). CBA allows quantitative analysis of a wide range of events. In CBA, the costs of the proposed policy are compared with the net benefits—only projects for which the benefits exceed the costs should be chosen. Among competing policy options each meeting this first criterion, the policy for which the difference between benefits and costs is greatest should be chosen (Stokey and Zeckhauser 1978). Alternatively, the use of CBA can be seen as a valuable exercise for thinking rigorously about the effects of one or more policy options, even if the final decision is made on more qualitative grounds. The difference between economists and ecologists are especially pronounced in their use and interpretation of CBA, as I show later in this paper.

In order to apply CBA, it is necessary to have a model predicting the costs and benefits associated with different policy options. There has been considerable recent work on modeling the cost of abating GHG emissions (Maddison 1995, Ausubel 1995, Dowlatabadi 1995). Generally, the analysis has fallen into two camps. Most economists have typically assumed a level of current technology and exogenous rates of technological improvement. These models have the advantage of being conservative about the potential for save-the-day technological fixes to our energy and GHG emissions problems. They typically assume that there is some minimal amount of inefficiency in the current system, yielding a potential for some abatement in GHG emissions at little cost, but that after that limitations on GHG emissions will tend to rise with increasing marginal costs (Hourcade et al. 1993). Another group of modelers, by contrast, has typically modeled using assumptions about what is technologically possible, if not currently available (Grubb 1995). These models have the advantage of treating technological change in particular areas as being highly affected by demand.[4] Nordhaus describes this as the difference between economic-optimization models, and engineering-optimization models. The former assume that markets and decisions are efficient, and there "are no costless GHG reductions (except in situations with classical externalities)" (Nordhaus 1993b, 36). The latter—the engineering studies—point to energy conservation and other efforts that could both reduce GHG emissions and lead to more efficient growth. Many economists would deride these studies as the view that not only are there free lunches, "but that in a selected set of restaurants you can get paid to eat" (Nordhaus 1993b, 36).

Several economists have applied CBA to more complicated questions, such as the value of waiting and learning more about climate change, as opposed to acting now. Manne and Richels (1991) use a two-period learning model, in which they assume that some learning would take place in the next twenty years. Given that learning, they decide upon the best policy option to be taken now. Peck and Teisberg (1993b, 1995) use a Carbon Emissions Trajectory Assessment (CETA) model to determine the value of information at different points in time. They find that the most gains to be made are in learning about the amount of warming to be caused by increasing GHG concentrations, and the magnitude and shape of the damage function associated with that warming. Kolstad (1993) adds on to an early DICE model, incorporating stochasticity, to find the value of information to be high if decisions to limit emissions are irreversible. Many of these models attempt to examine the role of "adaptive management" (Walters 1987) in the climate change issue, either explicitly or implicitly.

There have three sets of criticisms of the use of CBA. The first set has focused on the methodologies used and assumptions made to perform CBA specifically for climate change. Schelling (1995) questions the traditional use of discounting to cover intergenerational time spans. He suggests that society should make judgments about whom we want to help—

[4] These models have also typically examined longer time horizons (Grubb 1995). This fact is consistent with predictions of cultural theory (*see* Thompson and Rayner 1998, Table 4.5).

ourselves, our contemporaries in other parts of the world, or our descendants—and use CBA to find the best way to do so, rather than model climate change with a discount rate applied to future generations. Grubb (1995) questions assumptions of exogenous carbon intensity improvements, and suggests that the principal costs associated with changing our energy system arise from the rapid shift from one equilibrium to another. The service industry, including the supply of energy, tends to show decreasing returns over short spans of time, but increasing returns at larger scales of analysis, and could therefore be at a sub-optimal equilibrium (Arthur 1988). It could be just as economically efficient for the United States to function at the much lower carbon intensity level of Europe or Japan, but changing the energy system to operate in this manner, and doing so quickly, could be costly. Repetto and Austin (1997) critique the sensitivity of economic climate change models to the underlying assumptions. They regress cost projections from an extensive number of economic models, using eight explanatory dummy variables representing optimistic or pessimistic assumptions about costs and benefits. They obtain an R^2 of 0.8, meaning that the assumptions alone account for most of the differences between model results.

A second set of criticisms looks at the application of CBA to decisions of large scale, including climate change. Munasinghe et al. (1996) note that while CBA is most often used for small projects, its use for climate change necessitates using general equilibrium analysis, which is more difficult. CBA typically looks only at net gains or losses, and not how wealth is redistributed. It assumes that the winners from a project can compensate the losers, such that some people are better off and nobody is worse off. As the “leaky bucket” metaphor shows, however, it may often not be possible for this to work in practice (Okun 1975). That is because wealth transfers always involve some loss of efficiency, or deadweight loss, because of distorted incentives and transfer costs. When governments undertake many small, independent projects, each of which generates net economic benefits, it often the case that local gains from some projects will cancel out the local losses from others, and everybody will be more or less better off. In the case of climate change, the effects of which are highly correlated with each other, Pareto improvement is a less likely outcome. Under a policy course that passes CBA, some people may still be significantly worse off than they would have been otherwise.

A third set of criticisms concerns the use of CBA in general. Ideally, CBA measures preferences in terms of changes in consumer surplus, represented by people’s “willingness to pay” for competing public and private goods, or “willingness to accept” compensation for the loss of a preexisting public good. One can criticize this approach to decision-making as anti-egalitarian, since the “willingness to pay” of wealthy people will likely overshadow that of poorer people. CBA will thus tend to favor the choices of the wealthy. The criticisms of CBA can extend deeper however, questioning the validity of the rational actor paradigm on which CBA depends. Indeed, CBA “shares the deeper shortcomings of the rational actor paradigm in that it ignores equity and fairness and does not allow for the intricacies of trust, liability, and consent, interwoven in a risk situation. In effect the rational actor paradigm acknowledges only one facet of the multifaceted reality that risk situations present and is not capable of addressing the cultural diversity that policymakers are finding they must acknowledge” (Jaeger 1998, 165).

Risk Aversion and Utility Functions

The use of CBA is potentially problematic when there is uncertainty over outcomes. That is because what economists try to optimize is not money (consumption), but utility (happiness). Economists have generally observed that the first unit of consumption matters more to people than the second and subsequent units; that is, people experience diminishing marginal utility returns from increases in consumption. Because of diminishing returns, most people demonstrate an aversion to taking risks. CBA needs to take this into account, and doing so requires making many assumptions about people’s preferences. One criticism of economics is that often makes the same assumptions for all people.

This aversion to is consistent with having a concave utility function, as shown in Figures 1 and 2. On Figure 1, utility is plotted as a function of consumption. The fact that the curve becomes flatter reflects the fact that smaller amounts of marginal utility come from increasing amounts of wealth. Figure 2 shows how this translates into a propensity for risk aversion. Imagine that a person faces a lottery giving equal chances of consuming *c* or *c'*. The expected outcome is denoted by *E(c)*, and would give utility *u(E[c])*. Because the utility curve is concave, this utility is higher than the expected value of the two possible utility outcomes, *E(u[c])*. Indeed, we can identify a certainty equivalent, *c.e.*, that provides the same utility as the expected utility of the lottery. This point, *c.e.*, represents less consumption than the expected amount of consumption of the lottery. The distance between *c.e.* and *E(c)* accounts for the existence of insurance markets. Indeed, authors have suggested that climate change policies be considered as a form of insurance (Manne and Richels 1991). In the case of climate change, for which the aggregate societal impacts are likely to be less than 1% of total wealth, the movement along either a social welfare or a utility curve is small, and the effects of the curve's concavity are minor. For economists, risk aversion plays a potentially minor role in climate change.

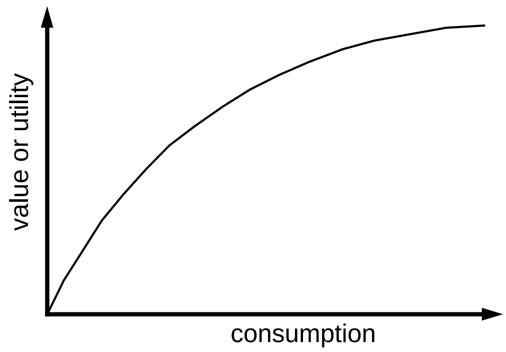

Figure 1: Concave Utility Curve

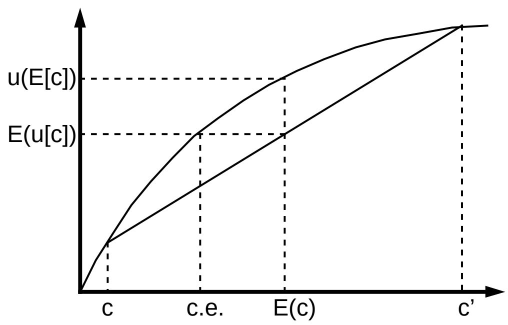

Figure 2: Diminishing Marginal Utility and Risk Aversion

When economists think about risk and uncertainty, they incorporate assumptions about the curvature of people's utility functions. When they apply this thinking to questions of social welfare, they make further assumptions about a "social welfare" function. In both cases, they use empirical findings to approximate what "typical" people value and prefer. Contrary to the axioms of economics, a great deal of psychological research has demonstrated that most people do not make decisions according to a single, well-defined utility function. Prospect theory, originally proposed by Kahneman and Tversky (1979), is one description of people's observed behavior. First, people tend to anchor their utility at their present level of consumption, and perceive changes in consumption in relation thereto. Second, people tend to care more about losing something they already have, than they do about acquiring something new. Third, while people tend to be risk averse for gains in consumption, they are "risk loving" for losses. Fourth, people place a great deal of emphasis on changes in assessed, or objectively measured, probabilities when the probabilities are close to 0% or 100%. Hence, people care much more about the difference between a 0% and a 1% chance of some outcome occurring than they do on the difference between a 35% and a 36% chance. Thus the small probability of a catastrophic outcome would be very important to people. The first three features can be seen in Figure 3. Utility is concave for points to the right of the origin, and convex and steeper for point to the left of the origin. The fourth feature can be seen in Figure 4. Here, "subjective" and "objective" probabilities do not necessarily correlate at a one-to-one ratio.

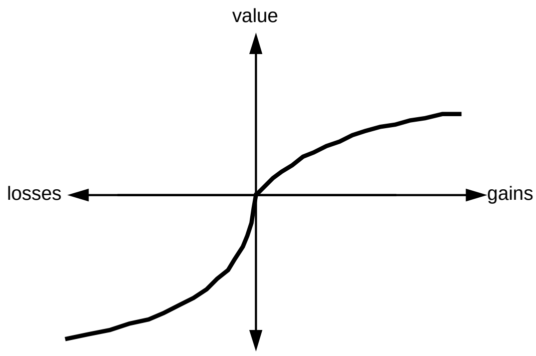

Figure 3: Prospect Theory Utility Curve

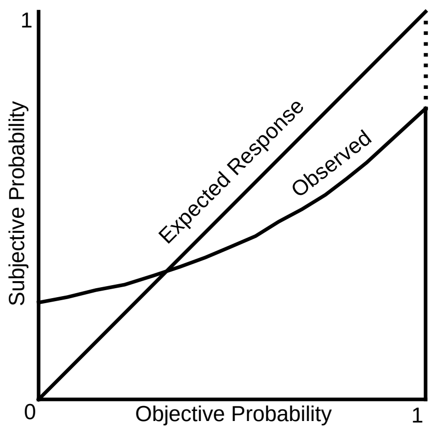

Figure 4: Subjective and Objective Probability

These observations come from controlled experiments and real world examples. In controlled experiments, doctors choose different treatments when the risks are expressed in terms of rates of survival or rates of mortality. People purchase lottery tickets, giving them a miniscule chance at a large sum of money, even when on average lotteries are a losing proposition. Daniel Ellsberg has explained the escalation of the Vietnam War according to prospect theory, and President Lyndon Johnson's willingness to risk large US losses rather than accept a minor defeat. Prospect theory does not say that people's inconsistent behavior is good or bad, but merely that it is a fact of life for most decision-makers. Prospect theory faces the same criticism as utility theory, however, for using a single model of the "person" (Douglas 1998).

Prospect theory has a number of implications for the politics of climate change. Subjectively, most people do not aggregate all costs and benefits into one lump, and then see how wealthy they expect to be under competing policy options. Rather, to the extent that they pay attention to economic models, they will consider how much they value the various categories of changes that each policy implies. They will then compare the various gains and losses in value to determine which policy they prefer. If we believe prospect theory, then it matters a great deal whether people perceive a particular policy as constituting a risk to future increases in consumption, or risking something that they already have. In the former case, they will tend to exhibit risk-averse behavior; in the latter, they will tend to demonstrate risk-loving behavior. Furthermore, losses will matter much more to people than gains, and will tend to drive the results of people's intuition. How climate change is framed is thus important.

Environmental economics developed around the analysis of regulations intended to reduce levels of pollution (Tietenberg 1988). In this case the status quo was clearly the pollution and the absence of environmental regulation. Environmental economists have generally framed the mitigation of climate change as a loss of economic surplus, and the results of those regulations as benefits (Munasinghe et al. 1996, Nordhaus 1994a, Tietenberg 1988, Hope and Maul 1995). They have tended to focus on uncertainty among the benefits of regulation, rather than the costs (Munasinghe et al. 1996, Pearce 1996). Nordhaus, for instance, identifies the issues that economic analysis of climate change seeks to address: whether to "intervene" to slow climate change; how much to "intervene"; choosing the most efficient policy instrument; achieving efficient and effective international cooperation; and, addressing uncertainty in the potential effects of climate change (Nordhaus 1993b, 32-33). Andrew Dean states it succinctly: "If climate change is going to damage the earth—and there is still much uncertainty about this—then one needs to be able to quantify the damage. Such costs, in the established language of climate change work, are the benefits of policies to slow the change, i.e. the damages avoided (Dean 1994, 26). This has potentially significant implications for intuitive responses to the problem.

For instance, imagine that CBA of a policy to prevent climate change revealed that the costs and benefits of that policy were exactly equal. A decision-maker ought to be indifferent between the particular policy and no policy at all—at least in economic terms—and should decide on the grounds of other considerations, such as equity. In fact, most people are likely to use their intuition to reject the particular policy in favor of no policy. On Figure 5, we can see that the improved environmental quality from the policy is framed as a gain. On the same figure, the costs to consumption of the policy are be framed as a loss, and will be kept in a separate "mental account" from the gains. To most people, things that are framed as losses are more important than things that are framed as gains. If we average the two changes in utility the result is a utility change that is negative, when compared with the status quo, the point of reference. Since the point of reference is no policy at all, most people will reject the policy to reduce climate change. Thus the "assumption" of what constitutes a gain and what constitutes a loss, really a judgment about what is the point of reference, will frame the issue in a way that favors no change in policy.

Ecologists are likely to frame the gains and losses the reverse of how economists do. They might perceive the environment, in its current state, as the point of reference. To the effect that climate change alters the environment for the worse, they will perceive a loss of something that they already have. For example, Mintzer (1987) models the degree of global "warming commitment" that current development policies are creating. For every year that current policies are in place, Mintzer projects an additional amount of future warming. Against this, he discusses the economic benefits that current policies allow. His is a perspective opposite to that of the economists; his point of reference is a world committed to preserving a sustainable climate, and policies that allow additional release of greenhouse gases are a departure from the norm, that ought to be justified before being pursued (Yohe and Cantor 1998).

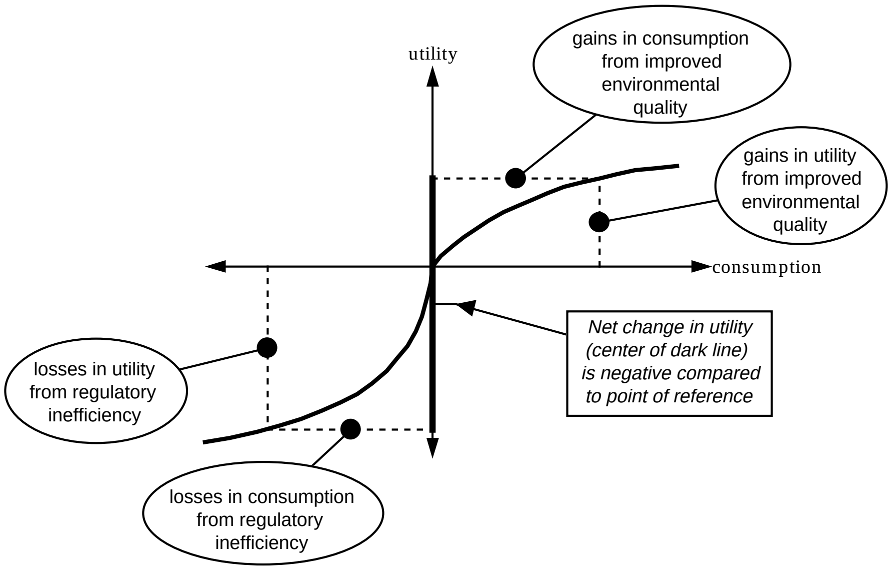

Figure 5: Economic Framing

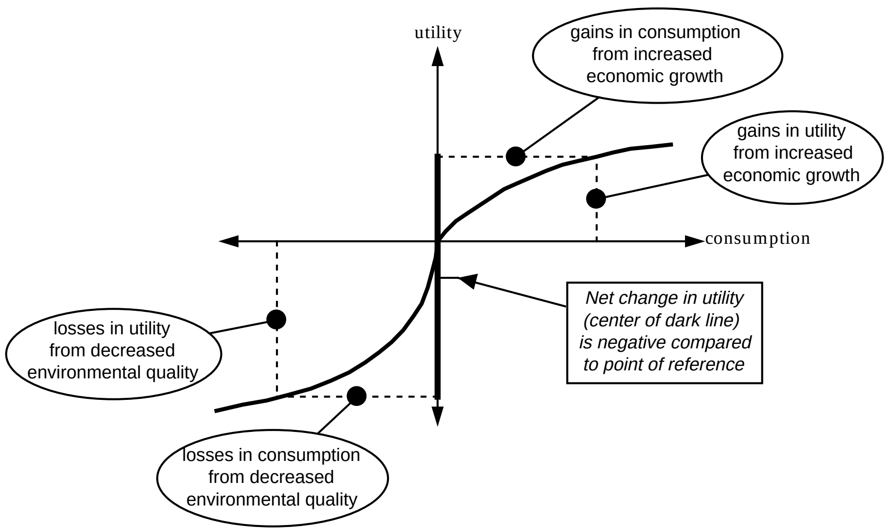

Figure 6: Ecological Framing

Ecologists may perceive the current standard of living as another point of reference. Improvements in that standard of living through economic growth will be gains; to the extent that efforts to curb climate change interfere with economic growth, the efforts may reduce those gains. Goldemberg (1988), for example, develops a bottom-up model of energy demand. He projects that industrialized countries can enjoy modest growth in per capita GDP while significantly reducing the demand for primary energy. Lesser-developed countries can raise their standards of living to levels approaching those of industrialized while increasing primary energy demand only slightly. His model asks what additional economic benefits (i.e. growth) can be gained while pursuing a more sustainable energy policy.

For ecologists, then, the point of reference is the policy that prevents climate change. Compared to that point of reference, the current policy of allowing climate change has associated with it various costs and benefits. On Figure 6, we can see that the added economic growth from the current policy is obviously a gain. Likewise, the expected environmental deterioration of the current policy is seen as a loss. As with the prior example, the losses are more important than the gains. When losses and gains are framed in this way, most people will prefer the point of reference, policies that preserve the environment, to the alternative, the current policy of allowing climate change to continue.

Discount Rates

Economists and ecologists might also reach different conclusions about climate because of how they discount the happiness of future generations. Most the effects of climate change will take place at least 50 or 100 years in the future. In order to avoid these effects, society may have to take action now. If one uses a high discount rate that is "too" high, then the costs of current action will appear too large relative to the costs avoided many years in the future. If the discount rate is "too" low, then the costs of current action will appear too small relative to the costs avoided many years in the future. Deciding what discount rate to apply can determine what policy appears to be optimal (Arrow et al. 1996, Lind 1995, Manne 1995, Toth 1995).

In order to develop a theoretical model of why economists might use a discount rate that is higher than that of ecologists, I start with the notion of a discount rate δ, which is the amount by which we choose to discount future utility. I can express the utility of an individual, or of a group of individuals as

$$u_0 = \sum_{t=1}^{\infty} \left(\tfrac{1}{1+\delta}\right)^t u(c_t)\,, \tag{1}$$

or in the continuous case, as

$$u_0 = \int_{t=0}^{\infty} u(c_t)e^{-\delta t}dt\,. \tag{2}$$

I assume a utility function (for individuals) or welfare function (for groups), $u(c_t)$, as a function of consumption in each time period, or in the continuous case at each moment of time. I impose two standard restrictions, which are consistent with standard utility theory (although the second-order condition is not consistent with prospect theory). They are:

$$\frac{du}{dc_t} > 0\,,\ \text{and} \tag{3}$$

$$\frac{d^2u}{dc_t^2} < 0\,. \tag{4}$$

Economists have noted that the amount by which we discount future utility should not necessarily equal the amount by which we discount future consumption (Koopmans 1960, Arrow et al. 1996). We derive less marginal utility as consumption itself rises, because of the falling rates of marginal utility expressed in equation (4). Arrow and Kurtz (1970) and others have pointed out that our social rate of time preference, ρ_t, depends on our utility discount factor δ, the elasticity of our marginal utility, θ, and expected changes in future consumption. Thus:

$$\rho_t = \delta + \theta(c_t)\frac{dc_t/dt}{c_t}\,. \tag{5}$$

Formally, we can express $\theta(c_t)$ as:

$$\theta(c_t) = -\left(\frac{d\left(\frac{du}{dc_t}\right)}{dc_t}\right)\left(\frac{c_t}{\frac{du}{dc_t}}\right), \text{ or} \tag{6}$$

$$\theta(c_t) = -\left(\frac{d^2u}{dc_t^2}\right)\left(\frac{c_t}{\frac{du}{dc_t}}\right). \tag{7}$$

From the inequalities in (3) and (4), we can determine the sign of $\theta\ (c_t)$:

$$\theta(c_t) = -(-)\left(\tfrac{+}{+}\right) > 0\,. \tag{8}$$

Thus:

$$\rho_t > \delta\ \ \forall \frac{dc_t}{dt} > 0\text{, and} \tag{9}$$

$$\rho_t < \delta\ \ \forall \frac{dc_t}{dt} < 0\,. \tag{10}$$

Our social rate of time preference will exceed our utility discount factor if we expect consumption to rise, and will be less if we expect consumption to fall. The magnitude of the difference is directly proportional to the rate at which consumption is changing.

There is, however, a considerable amount of controversy over what discount rate δ touse for utility. A number of economists have argued for an intergenerational utility discount factor of zero (Cline 1992, 1993). They argue that we ought to count the happiness of future generations as much as our own. More typical proposals for the utility discounting factor have ranged from 1% to 3% (Nordhaus 1994a). These proposals also note that if we invest money in productive capital, it can earn a return approaching 10%, far in excess of the rates proposed by Cline. Finally, a number of economists and psychologists have noticed that people demonstrate internally inconsistent rate of time preferences. Typically, people apply a higher rate of time preference for consumption in the near future than they do for consumption occurring later on (Arrow et al. 1996). For instance, a person might prefer $100 today to $101 tomorrow, but prefer $101 several months from now to $100 one day earlier.

However, even if people are able to agree on what rate to apply to utility, they are likely to disagree over how much they expect future consumption to rise and marginal utility to fall. To the extent that disagreement correlates with whether one is an economist or an ecologist, the two disciplines will tend to apply different social rates of time preference. It does correlate, for three reasons. First, economists and ecologists who are alive today have different values. Economists tend to see the world in terms of economic growth, and tend to project increasing consumption of market goods. Ecologists, however, are likely to be acutely aware of resource depletion and degradation (Yohe and Cantor 1998). Indeed, they may feel that “natural capital is rapidly becoming more and more scarce and it is inappropriate to calculate the net benefits of a project or policy alternative by comparing it with unsustainable options” (Yohe and Cantor 1998, 82). They may place great weight on the existence of public environmental quality, and equate the loss of this quality with falling levels of consumption. Ecologists, because they likely derive a large proportion of their utility from environmental quality, are likely to apply a lower social rate of time preference to their decisions.

Second, economists and ecologists who are alive today are likely to imagine themselves as having even more different values twenty years from now. Economists tend to model people as having diminishing returns to total consumption. Ecologists, however, are likely to believe that assumptions of declining marginal rates of utility may not be accurate for long-term decisions about the environment (Yohe and Cantor 1998). If people do anchor their utility at their present level, then it is reasonable to expect them to show decreasing marginal utility only relative to their current consumption level. For instance, imagine that my present consumption is $1000, and that I take a daily walk in the park. The added utility I will get from the first additional dollar (from $1,000 to $1,001) is greater than the added utility I get from the second additional dollar (from $1,001 to $1,002). However, over time I readjust my expectations. Suppose, a year from now, I consume $1,100. Again, the added utility from the first additional dollar ($1,100 to $1,101) exceeds the next additional dollar. However, because I have readjusted my expectations, we can not necessarily say that the utility change from $1,000 to $1,001 or $1,002 exceeds that from $1,100 to $1,101 or $1,102. Indeed, it may be that once I have readjusted my expectations, an additional dollar will have the exact same effect. Ecologists may be reluctant to assume that people exhibit diminishing marginal returns as they grow wealthier.

Finally, economists and ecologists that are alive today are likely to project very different values on future generations. Economists tend to model people as having relatively stable preferences over time, in the absence of evidence to the contrary. However, even if people experience decreasing marginal utility from wealth, they may derive increasing marginal utility from environmental quality as their wealth increases. Thus the walk in the park, from the last paragraph, is more important to the person who is wealthy than to the person who is worrying about his or her next meal. This is consistent with the observation that the environment is a luxury good—the more wealthy a society is, the greater the emphasis it places on environmental quality (Tietenberg 1988). Ecologists may intuitively understand that future generations, which are likely to enjoy higher material standards of living, will derive greater enjoyment from environmental quality relative to other forms of consumption. Thus, ecologists may believe that it is more important to leave future generations high levels of environmental quality than it is to leave them other forms of capital stock. Indeed, ecologists argue that "natural capital and human-made capital are largely complements (rather than substitutes), and that natural capital is increasingly becoming the limiting factor for further development" (Yohe and Cantor 1998, 82). Because they do not convert the enjoyment of public and private goods into a single metric, total consumption, ecologists are likely to apply a lower social rate of time preference to the environment than they do to other forms of consumption.

Cultural Theory

Cultural theory has long attempted to explain the differences in assumptions that I examine in this paper. First proposed by anthropologist Mary Douglas (1978), cultural theory maps different people's beliefs according to "grid" and "group". Grid refers to the constraints people perceive on their behavior. Group refers to people's level of social connectedness. According to cultural theory, where a person or a social discourse falls on the grid-group space correlates highly with the attitudes towards a number of social and environmental concerns. As a general heuristic, cultural theory defines four types of social solidarity, shown in Figure 7.[5]

For example, cultural theory correlates each of the social solidarities with a different "myth" of nature. Individualists, who see nature as "benign", perceive it as always returning to a stable equilibrium. Hierarchists see nature as stable within identifiable boundaries—the role of rules is to make sure that nature stays within those bounds. Egalitarians see nature as inherently unstable, and believe that we need to be careful to maintain the current precarious equilibrium. These attitudes are shown in Figure 8.

It is easy to say that economic discourse follows individualist lines-and thus sees nature as benign-while ecological discourses are more egalitarian. Saying this, however, falls victim to a major criticism of cultural theory: that it is tautological (Boholm 1996). One's expressed attitudes towards social and environmental issues determine where on the grid-group map one falls. This location, then, predicts one's attitudes towards those same social and environmental factors. According to this criticism, then, cultural theory has no predictive power. In order to make my analysis robust to this criticism, I do not use cultural theory explicitly to explain the different assumptions and conclusions of economists and ecologists. I do use cultural theory,

[5] Depending on the author, article, and year, cultural theory sometimes uses threefold or fivefold classification systems. In this paper, I use the fourfold system that has become the industry standard.

however, as an organizing framework for expressing uncertainty. Using this framework, I develop a set of assumptions that are different from those of economists, and yet can be used in the economists' own models. In the following section, I do this for a modified version of Nordhaus' DICE model.

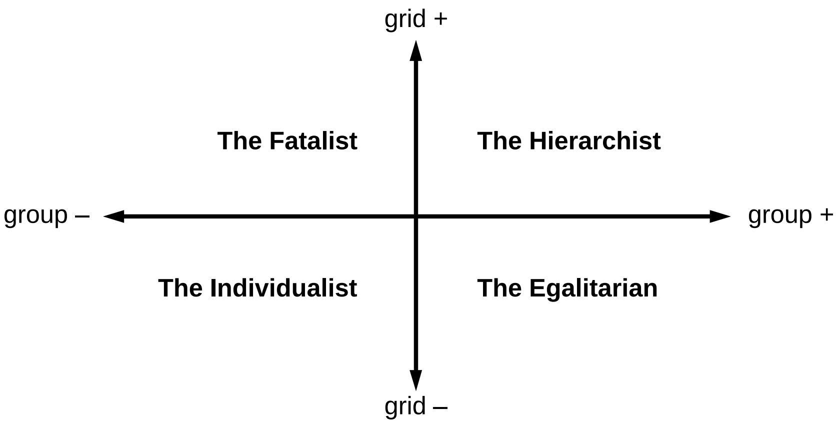

Figure 7: Grid/Group Analysis

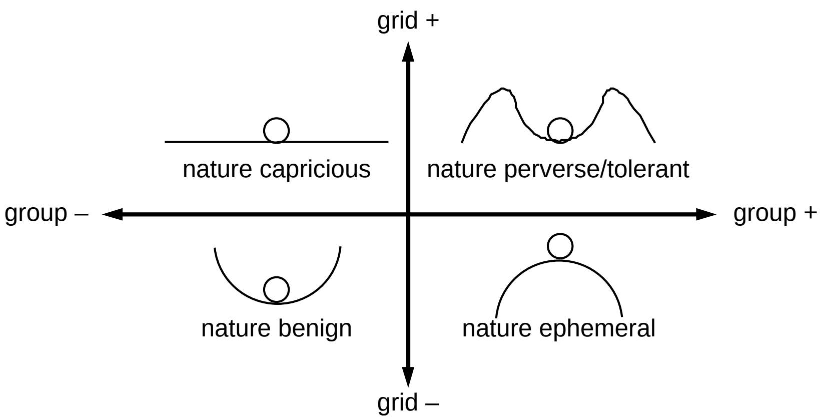

Figure 8: Cultural Theory Myths of Nature

Application

Using Economists' Assumptions

To illustrate how economists and non-economists would arrive at different results with CBA, I use a simple model of climate change.[6] The model, and its baseline parameter values, is similar to Nordhaus' (1994a), although some of the equations in my model are slightly different, to account for endogeneity of damage and control costs. The DICE model has been very influential in the climate debate, perhaps the most so among economic models. It has been criticized for underestimating the magnitude of the climate change problem (Kauffman 1997) and for

[6] I present the derivation of the model and its parameter assumptions in the appendix.

overestimating control costs (Grubb 1995). Nevertheless, it provides a good starting point for analyzing the differences between economic and ecological assumptions.

For illustrative purposes, I assume a choice between five policy options. The first option, “none”, is to continue economic development along its present course. Any policy measures addressing climate change would take the form of *ex post* adaptation, rather than *ex ante* mitigation. The emissions generated under this scenario are what I later refer to as baseline emissions. The second policy response, what I label “no regrets”, would be to make a small effort now to reduce greenhouse emissions.[7] This corresponds closely to the policy response that Nordhaus (1994a) also finds to be optimal. It represents a 10% reduction in baseline carbon emissions, phased in over ten years, beginning in the year 2,000. The third policy response I label “now”. It represents a 50% reduction in baseline carbon emissions, implemented rapidly in the year 2,000. The fourth policy response, which I label “gradual”, also represents a 50% reduction in baseline emissions. These reductions take place uniformly over the course of 50 years, beginning in the year 2,000. The final policy option, which I label “later”, represents a 50% reduction in baseline emissions, taking place in the year 2,050.

I model the effects of these policy options across four potential states of the world, representing uncertainty over the sensitivity of climate to greenhouse gas emissions. In the first state of the world, the greenhouse effect does not exist—temperatures do not rise with changes in greenhouse gas concentrations. In the second state of the world, approximately representing the low end of Houghton et al. (1996) estimates, mean global surface temperatures eventually will rise by 2.0° C in response to a doubling of greenhouse gas concentrations. In the third state of the world, approximately representing the Houghton et al. (1996) median estimate, mean global surface temperatures will rise by 3.0° C in response to the same doubling. In the fourth state of the world, representing the high end of the Houghton et al. (1996) estimates, temperatures will rise by 4.5° C.

The model projects world consumption through the next 400 years. It then calculates the corresponding aggregate utility, which it discounts at 3% per year. It then takes the sum of discounted utilities for the five policy response scenarios, across the four different potential sensitivities of climate to greenhouse emissions. The model treats baseline utility as that occurring with zero climate sensitivity and no policy response. All other utilities are presented as a fraction of that baseline utility. Figure 9 shows the results.

The model projects that the best policy option is either none at all or the no regrets response, depending on the sensitivity of climate to greenhouse gas concentrations. This result is consistent with that of Nordhaus (1994a), and many other economic assessments, including Bruce et al. (1996). If the climate is insensitive, no response is clearly best. For the other three climate sensitivities, the no regrets response is the best. In all cases, the three major reductions in greenhouse gas emissions are worse than no response at all. The worst policy is immediate, large-scale cutbacks; indeed the magnitude of the economic setback this policy would produce far exceeds the potential setback from climate change itself. If we are to reduce greenhouse gas emissions by 50%, the best thing to do is to wait as long as possible before doing so.

[7] The term “no regrets” comes from the notion of being able to take a limited amount of action that is cost effective even if climate change is not a problem. If we assume that there are some preexisting market inefficiencies—from tax policy, externalities, or imperfect competition—then it is possible that certain policies could lead to increased short term efficiency.

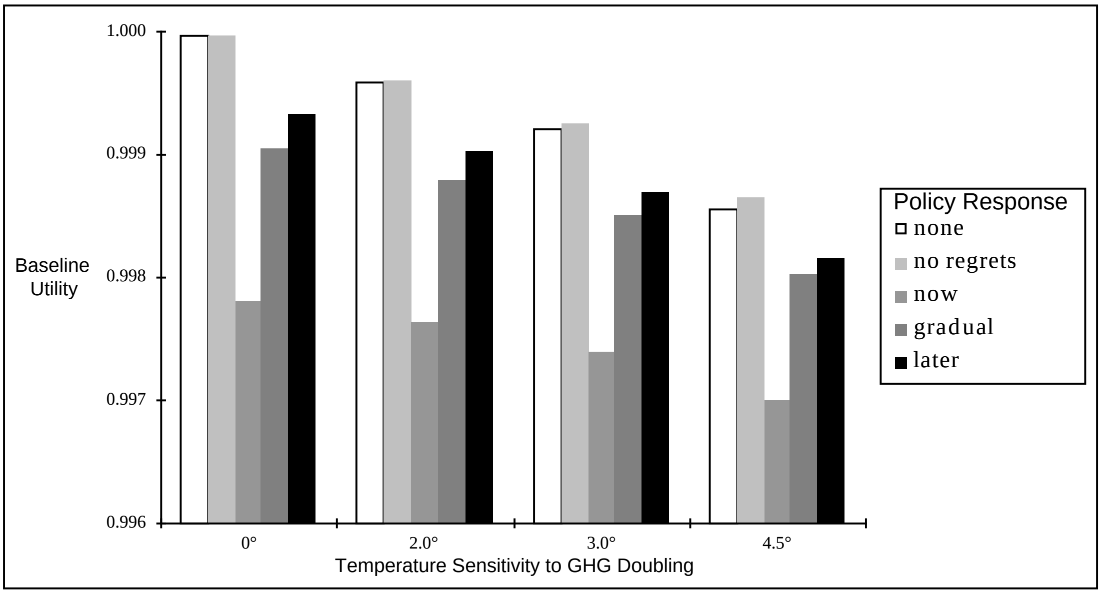

Figure 9: Model Using Economic Assumptions

Using Other Assumptions

I test the model for its sensitivity to the standard economic assumptions by running it with different parameter values, and with uncertainty expressed across different dimensions. While economists have typically modeled uncertainty in terms of different climate sensitivities to changing greenhouse gas concentrations, ecologists are more likely to consider different ecosystem and societal impacts associated with a given amount of temperature rise. Thus, I treat as given the Bruce et al. (1996) middle scenario of 3.0° C, but use a range of estimates about the costs of both total and incremental temperature changes. This represents uncertainty about the stability of the system as a whole—whether it is one that is fundamentally in equilibrium, or whether it is one that could tip fairly easily. I also express uncertainty in the cost of reducing greenhouse gas emissions.

I model four states of the world to represent the different world views of cultural theory (Douglas 1978, Schwarz and Thompson 1990, Thompson and Rayner 1998). The first state of the world, which I call individualist, is that of the economists. This represents a belief that ecosystems are generally stable, but that the costs of emissions abatement rise quickly and non-linearly with the amount of abatement. The parameters in the second scenario, the fatalist, are similar to the first, except that emissions abatement costs are linear. Hence, it does not matter as much what policies we adopt. The third scenario, the hierarchical, differs in two respects. First, the cost of greenhouse gas abatement is a function not of total abatement, but only of incremental abatement. This represents the view that social systems face some management costs in switching to new methods of production, but if done correctly the long run will be just as efficient as with the old methods. Second, the costs associated with incremental temperature change have been increased by one order of magnitude. This represents the view that nature may be somewhat unstable in the face of large perturbations, and that for rapid changes in temperature there may be drastic implications for society. The egalitarian scenario assumes that there are no net costs associated with reducing greenhouse gas emissions—technology improvements in the direction of clean energy such as solar and wind are completely desirable for other reasons. Furthermore, the cost of incremental temperature change has been increased by another order of magnitude. This represents the idea that nature is very unstable, and could generate catastrophic outcomes in response to modest changes in mean surface temperatures

Finally, I capture some of the discussion over discount rates by using a variable discount factor. Instead of discounting all time periods at 3.0%, I discount the first 50 years at 3.0%, the next 50 years at 2.0%, the next 100 years at 1.0%, and all subsequent years at 0.5%. This better approximates people's own intuitive discounting of future utility (Arrow et al. 1996). Although it would be best to discount consumption at one level, and environmental quality at another, the model is to simplistic to disaggregate goods in this manner.[8] Figure 10 shows the results of the model. I present the same five policy options as in the prior section. Again, all utilities are expressed as fractions of baseline utility, which in this case is no policy response under the individualist scenario.

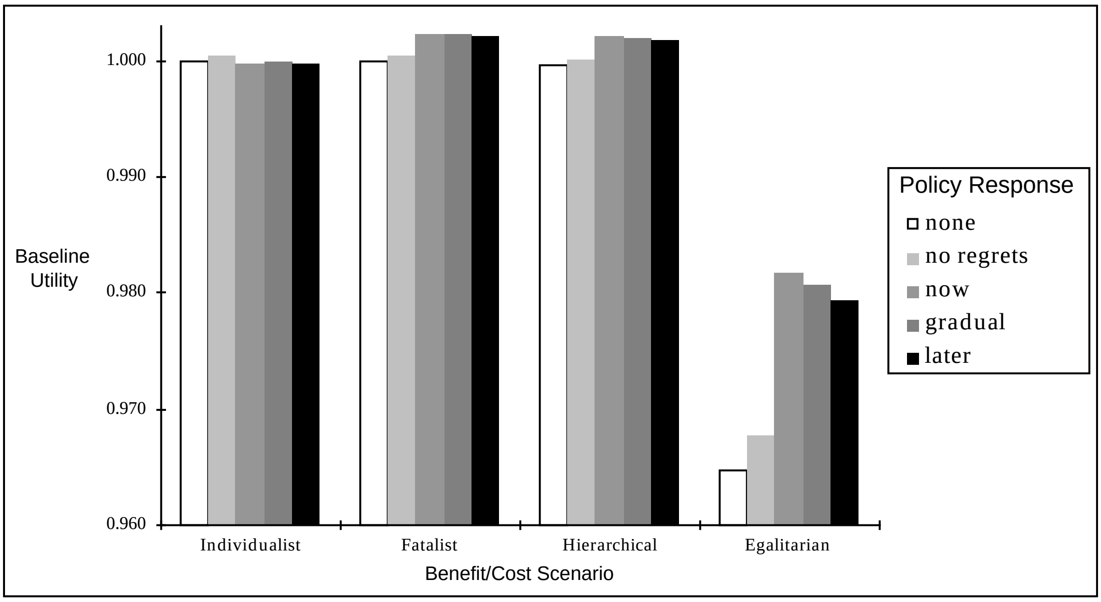

Figure 10: Model Using Ecological Assumptions

The individualist scenario looks very much like the results of the prior model. The no regrets policy response is the best, and the large-scale immediate cutbacks are the worst. In the remaining three scenarios, however, the ordering of the policy options is reversed. The best policy option is the immediate reduction of emissions by 50%. This is followed by gradual large-scale reduction, delayed large-scale reduction, and then the no regrets policy response. The worst thing is to do nothing at all. In the egalitarian scenario, the implications are the most pronounced.

Interpreting the Model

The results generated by the model can and will be interpreted differently by different people, each of whom is acting responsibly and intelligently. A reasonable response for economists is to trust the results of the first chart, Figure 9. These results were produced using the best available estimates of costs and benefits of climate change policies. Obviously the model could be improved upon, and we should expect that to happen over time. As scientists learn more about climate change, we will see greater certainty about the magnitude of temperature changes. That

[8] Likewise I do not differentiate between the scenarios when it comes to discount rates. The scenarios represent the potentially different outcomes of climate change, depending on how nature and human systems actually respond. Discount rates are subjective, and therefore do not possess the same type of uncertainty. Note that cultural theory does predict different treatment of time and discounting by each of the four world views (*see* Thompson and Rayner 1998).

is, we will see the variance of future estimates to shrink, and the median estimate to either rise or fall, but the expected value of the median estimate to remain constant. Since the best response to any of our likely scenarios—either 2.0°, 3.0°, or 4.5° C—is the no regrets policy response, that is the one that we should adopt. Because the future may surprise us, and our median estimate may change substantially, we should be prepared to alter our future emissions strategy. Furthermore, if we learn more about the costs and benefits of policy options, we should be prepared to alter the parameters of our model, and potentially change our emissions strategy. Again, future estimates of costs and benefits will likely change, but if our present analysis is correct the expected—or average—change should be zero.

Ecologists, however, might come to different conclusions. These conclusions will depend on two patterns of thought. First, the conclusions will depend people's perception of risk. Ecologists are likely to take a risk averse stance toward climate change. This will be most pronounced if they perceive the effects of climate change to be losses in their standard of living, and the benefits of uninterrupted economic growth to be gains. As modeled by economists, risk aversion should take into account the probabilities associated with the likely outcomes of climate change, and weight each potential outcome accordingly. In practice, most people tend to over-weight the likelihood of low probability outcomes (Kahneman and Tversky 1979). In some cases, very unlikely consequences of climate change will shape people's subjective impression of the issue (Patt 1997). For this reason, the egalitarian scenario on Figure 10 is likely to play an important role in shaping people's responses. Even if the individualist scenario, the one derived from the best estimates of the economic effects of climate change, is the most likely, the possibility of more catastrophic outcomes may determine the choice. Even if the egalitarian scenario is highly unlikely, its mere possibility will shift the certainty equivalent for the five policy options. More importantly, ecologists are unlikely to take the model's representation of aggregate utility at face value. They are likely to ask "What will climate change do?" and "What will it take to stop it?" They will then place answers to these two questions in separate mental boxes, comparing them in accordance with the general descriptions of prospect theory.

The second, and more complex, account of why ecologists may prefer the substantial policy options derives from their impressions of scientific and mathematically derived information. Ravetz (1990) discusses the notion of the quality of scientific information. He develops a framework for categorizing information according to its numerical quantity, and three different descriptions of its reliability: spread, assessment, and pedigree (Ravetz 1990). The first concept, spread, is similar to the confidence bounds often presented with statistical information. The second concept, assessment, represents the level of aggregation at which the original data were measured. The final concept, pedigree, represents the level of acceptance within varying subsets of the scientific community that the data command. In the case of climate change, it is important to recognize the limitations of the inputs to the model. In understanding the uncertainty associated with the model, we should understand the processes at which the various parameters were estimated. The range of temperature responses to a doubling of greenhouse gas concentrations, for instance, came about through the use of general circulation models of air and ocean currents. These are limited in their degree of complexity by the speed of the computers on which they are run. Furthermore, the numerical range has not changed, even as the models themselves have produced different outputs over time; this may reflect the politics of publishing official estimates of climate change impacts (Van der Sluijs et al. 1997). Other parameter estimates were arrived at through equally problematic methods, or with equal imprecision. Estimates of mitigation costs, for example, are generally made at the level of one or two significant digits. For example, an estimate of 2% of GDP means that the value could be anywhere between 1.5% and 2.5%. This represents an uncertainty of nearly 50% of the value of the parameter itself. According to Ravetz (1990), the model's final output is only as accurate as the weighted uncertainties in the inputs allow.

In prior sections, I presented the results of the model so as to maximize, visually, the variance between the different policy responses, scaling the charts to show only the top 1% of baseline utility. It would be equally legitimate, however, to present the model output scaled over the full range of possible values, from 0 to 1. Figure 11 is a re-scaled version of Figure 9, and Figure 12 is a re-scaled version of Figure 10. Looked at in this manner, it may not matter very much, from a perspective considering net effects, what we do about climate change. The differences between the outcomes of different policies are completely overshadowed by the uncertainties in our original data.

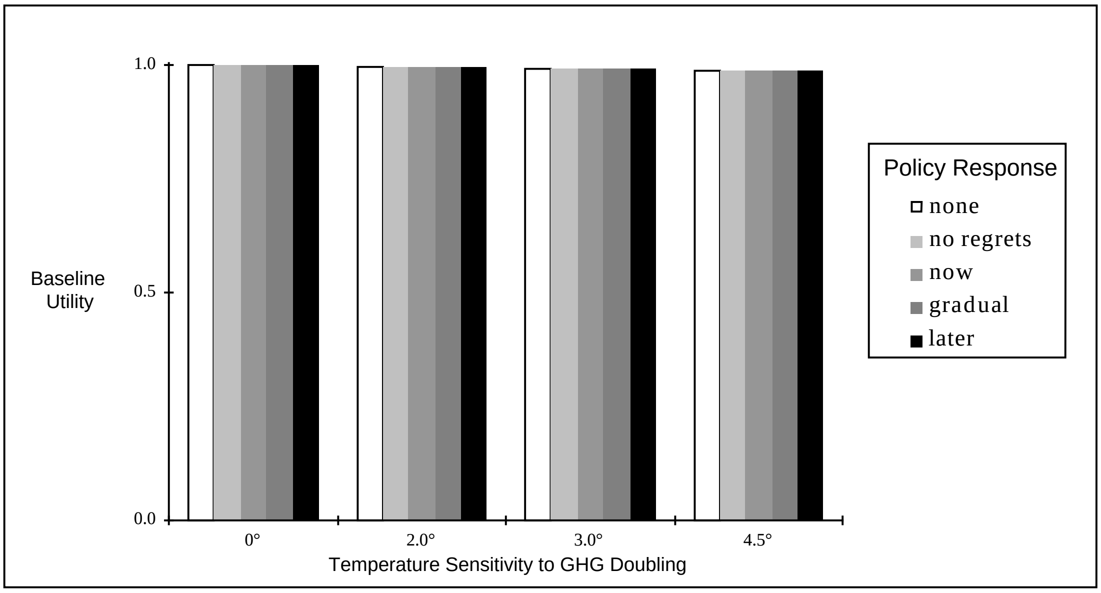

Figure 11: Rescaled Model Using Economic Assumptions

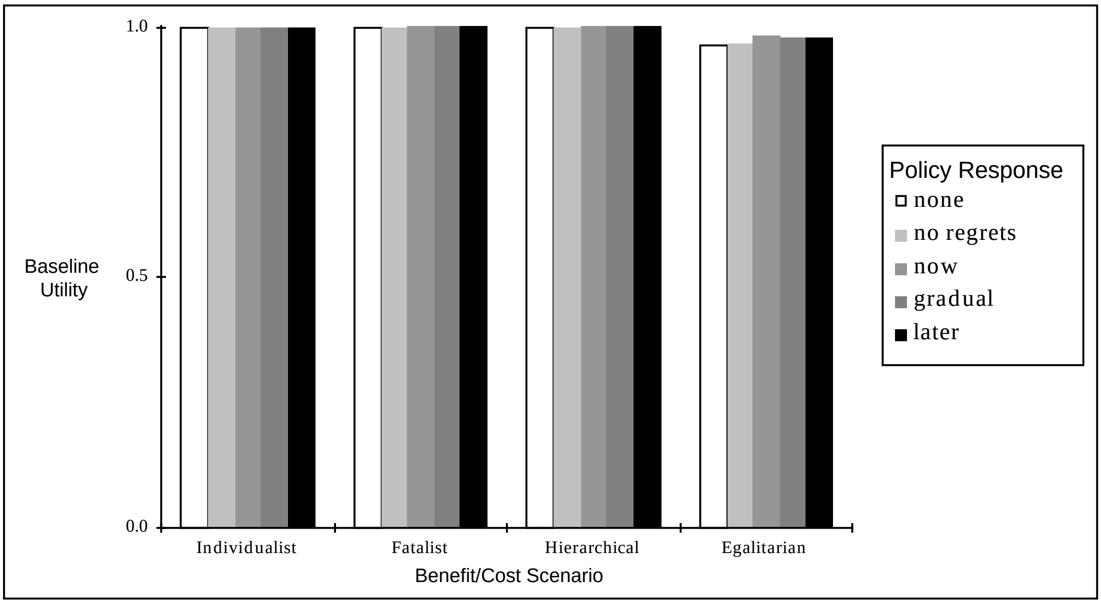

Figure 12: Rescaled Model Using Ecological Assumptions

Conclusion

No issue is certain or easy. Climate change is more difficult, and less certain, than most. First, climate change has the potential to cause catastrophic change, or very little change at all. Second, implementing policies to reduce climate change will take an unprecedented level of global cooperation. Third, taking steps to reduce greenhouse gas emissions will necessitate restructuring of energy systems across the world. The list goes on. Through the IPCC and other assessment panels, a tremendous amount of information, much of it conflicting, has been generated to address the issues that climate change raises. However, different people have consistently interpreted that information in different ways. Some have called for rapid and widespread policy actions. Others have urged caution. To many people, it has seemed like the different groups have not been able understand each other at all, and emotions have run high.

If policy makers are to make sound decisions to address climate change, they not only need good information, they also need to know how to use that information. The purpose of this paper has been to show how different groups of people might use information differently. First, they might perceive of costs and benefits differently, and assign risks to different aspects of climate change policies. Second, they might interpret the passing of time differently, assigning different weights to present and future generations. I have attempted to demonstrate, through my interpretations of a computer model, how these people could arrive at different viewpoints while using the same tools.

In terms of aggregate utility, a wide range of policy options generates essentially identical results. We know, however, that these policy options are likely to have major impacts across different sectors of society. For instance, the model that I have used predicts that reducing greenhouse gas emissions by 50% in the year 2,000 will result in temperatures about 2° C lower than if we do nothing. This could mean the difference between flooding coastal regions, or not. As another example, we know that reducing greenhouse gas emissions by 50% is likely to involve a radical restructuring of industrialized countries' energy systems. There may be economic winners in this process—the owners of technology to produce renewable or nuclear energy, for instance—but there will also be losers, such as owners of oil and coal reserves. Deciding whether to undertake major changes depends on how we view, and wish to affect, these various groups of people and social systems.

Economic models of climate change at the regional level generally predict the damages to tropical, coastal, and developing countries to be large (Mendelsohn et al. 1997). These countries are often heavily reliant on agriculture, which will suffer most. They are also vulnerable to sea level rise, and increased storm surges. While some models predict that developed countries will also suffer losses from climate change, others predict modest gains due to warming of high latitude regions (Mendelsohn et al 1997, Mendelsohn and Neumann 1998). If we believe the analysis of Grubb (1995) or Arthur (1988), the main costs associated with avoiding climate change will be in switching from one local equilibrium to another. Hence the industrialized countries, which are already heavily invested in fossil fuel energy production, will bear the brunt of the costs of changing course. We need to decide the relative merits we give to equity and to efficiency. If we envision a future of greater equity than today, it may be more efficient to achieve that through avoiding climate change, than by allowing climate change and then making *ex post* wealth transfers.

Ecologists and others are likely to argue that other factors, which are not easily measured by economists or captured in economic models, should determine our policy choices. Even if climate change itself is likely to be minor, a lot of people spend a lot of time worrying about it. Perhaps alleviating this worry should be the basis for action. Rayner (1995) argues that even if the climate change problem did not exist, we would have to invent it. That is because the world now faces the need for some policy problem to be the basis for global environmental governance. The experience with institution-building and -maintenance that climate change provides will be the principal legacy of the climate change problem. The effectiveness with which society responds to climate change will directly or indirectly influence how well society can respond to other issues of global significance. Wynne (1996) and others argue that risks themselves are "socially constructed". Thus, what the real implications of climate change are, along with their associated probabilities, depend less on natural forces than on how people perceive them.

Even if economists don't have much to say about the problem of climate change as a whole, ecologists still admit that they are still relevant when it comes to sorting out the details. For instance, economic analysis can show what methods of controlling greenhouse gas emissions are likely to be the most effective, and come at the lowest cost. Economic analysis will also show where the economic impacts from climate change, and efforts to control climate change, are likely to be severe. Thus, "applying the foundations of economic efficiency to the construction of global policy can produce dramatic results, even if the prescribed policy targets are drawn from outside what might be supported by the economic paradigm" (Yohe and Cantor 1998, 90). If society is to deal effectively with climate change, it will need economic analysis to do it well.

Appendix—Mathematical Model of Climate Change

The model I use here predicts the economic impacts of different policy and state-of-the-world scenarios involving global climate change. It is very simple in its form, aggregating the entire world into one region, and dealing with the economy as a whole. While the model allows for some representation of uncertainty, it does not allow for stochastic uncertainty within a probability distribution. It is largely based on the Nordhaus (1994a) DICE model, which is the latest in a series of models built by Nordhaus (1993a, 1992, 1991b). Indeed, unless otherwise noted, all equations are taken from Nordhaus (1994a). The computer version of the model is programmed in Microsoft Excel, on the Macintosh / Windows platform.

Climate Change Equations

The model begins with an equation accounting for the increase in carbon concentrations due to anthropogenic sources of greenhouse gases (GHGs):

$$M_t - 590 = \beta E_{t-1} + (1-\delta_m)(M_{t-1} - 590). \tag{11}$$

Equation (11) describes the interaction between human emissions of GHGs and their concentration in the atmosphere. In equation (11), t describes time, which I measure in years. M_t is the atmospheric accumulation of GHGs, in billions of tons (Gt) of carbon equivalent. E_t is the rate at which humans are emitting carbon or its equivalent. Of the carbon emissions that humans pump into the air, a fraction β remain in the atmosphere until the next period; those that survive until the next period are then removed at a rate δ_m, the value of which reflects a half-life of approximately 100 years. Pre-industrial levels have been estimated at 590 Gt. The value for M_t in 1995 has been estimated at 764 Gt. E(0) would be the rate of carbon emissions today, which I take to be 8.0 Gt. per annum (IPCC 1996).

$$E_t = \sigma_t (1-\mu_t) Y_t. \tag{12}$$

Equation (12) describes GHG emissions as a function of economic output, carbon intensity of the economy, and the policy in place at time *t*. Y_t describes gross world output, measured in trillions of 1989 US$. The control variable μ_t represents the policies in place to limit carbon emissions, expressed as a fraction of their baseline amount. The state variable σ_t measures the carbon intensity of economic output, measured in Gt per $1989 trillion. Note that σ_t is an exogenous variable which follows an asymptotically decreasing path. This can be expressed as:

$$\sigma_t = \sigma_0 \exp\left(\tfrac{\gamma_\sigma}{\delta_\sigma}\left(1 - \exp(-\delta_a t)\right)\right), \tag{13}$$

where γ_σ and δ_σ are parameters reflecting initial growth rates and slowdown in growth rates. This leads σ to decrease in the limit towards $\sigma_0 \exp(\frac{\gamma_a}{\delta_a})$ as $t \to \infty$. Likewise Y_t also varies across time, although its growth represents a combination of endogenous and exogenous factors.

$$Y_t = \left(A_t^* N_t\right)^{1-\theta} K_t^\theta. \tag{14}$$

In equation (14), N_t represents the population, K_t is total accumulated capital, and A_t^* is the net productivity of labor. Equation (4) is a general Cobb-Douglas production function of constant returns to scale, where θ and $1-\theta$ are the relative productivity of labor and capital. Capital can be assumed to grow during each period as a function of output, Y_t, accumulated capital, K_t, consumption, C_t, and depreciation, δ_k:

$$K_{t+1} = K_t\left(1-\delta_k\right) + Y_t - C_t. \tag{15}$$

In equation (15), δ_k is an invariant parameter, while C_t is one of two control variables. Thus one source of the endogeneity in Y_t is the control variable C_t. Another, however, is the variable of labor productivity, which depends, among other things, on the level of climate change and control of climate change.

$$A_t^* = \left(1 + \tfrac{D_1}{9} T_t^2 + D_2 \left[T_t - T_{t-1}\right]\right)^{\frac{-1}{1-\theta}} \left(1 - b_1 \mu_t^{b_3} - b_2 \left[\mu_t - \mu_{t-1}\right]\right)^{\frac{1}{1-\theta}} A_t \,. \tag{16}$$

A_t is the exogenous change in labor productivity, and $\left(1 - b_1 \mu_t^{b_3} - b_2 \left[\mu_t - \mu_{t-1}\right]\right)^{\frac{1}{1-\theta}}$ is an endogenous change due to control costs. Here, b_1 and b_2 are parameters describing the weight and total cost of implementing total levels of control, and incremental amount of control. The total level of control is raised to the power b_3. In accordance with Nordhaus' estimate we set at 2.887. The inclusion of incremental amounts of control represents the fact that costs are driven by the total amount of control in place as well as by the rate at which control is instituted. The latter is an approach used by Grubb (1995), and differs from that of Nordhaus (1994a).

The expression $\left(1 + \tfrac{D_1}{9} T_t^2 + D_2 \left[T_t - T_{t-1}\right]\right)^{1/1-\theta}$ accounts for losses due to temperature rise, and is a function of the square of total temperature increase and the temperature increase during the most recent period. D_1 and D_2 are parameters weighting the relative importance and absolute magnitude of both damage elements. This differs from the Nordhaus model in the addition of D_2 and the one-period temperature increase, and reflects more recent thinking about the true impact of temperature change on economic productivity. The A_t and N_t appearing in equations (14) and (16) both follow a growth pattern similar to that for σ_t, thus:

$$N_t = N_0 \exp\left(\tfrac{\gamma_n}{\delta_n}\left(1 - e^{-\delta_n t}\right)\right), \text{ and} \tag{17}$$

$$A_t = A_0 \exp\left(\tfrac{\gamma_a}{\delta_a}\left(1 - e^{-\delta_a t}\right)\right). \tag{18}$$

These imply that as $t \to \infty$, N_t approaches $N_0 \exp\left(\tfrac{\gamma_n}{\delta_n}\right)$ and A_t approaches $A_0 \exp\left(\tfrac{\gamma_a}{\delta_a}\right)$, reflecting growth that moves asymptotically towards an equilibrium level. Equation (6) also depends on the total and marginal rise in temperature at time t.

$$T_t = T_{t-1} + (1/R_1)\left[F_t - \tfrac{1}{\lambda} T_{t-1} - \left(R_2/\tau_{12}\right)\left(T_{t-1} - T_{t-1}^*\right)\right], \text{ and} \tag{19}$$

$$T_t^* = T_{t-1}^* + \left(1/R_2\right)\left(R_2/\tau_{12}\right)\left(T_{t-1} - T_{t-1}^*\right). \tag{20}$$

T_t in equations (19) and (20) is the rise in mean global surface temperature, while T_t^* is the rise in deep ocean temperature. λ is the equilibrium change in temperature for a given change in atmospheric concentration. R_1, R_2 and τ_{12} describe the thermal capacities of the surface atmosphere, the deep ocean, and the rate of energy transfer between them. F_t measures radiative forcing.

$$F_t = 4.1 \times \log(M_t / 590) / \log(2) + O_t \,. \tag{21}$$

$$O_t = \begin{cases} .2604 + .0125\,t - .000034\,t^2 & \text{if } t < 150 \\ 1.42 & \text{otherwise} \end{cases} . \tag{22}$$

O_t represents the combined radiative forcing due to exogenous factors. I express the control problem as being that of maximizing aggregate consumer utility over the infinite future.

$$\max_{C_t, \mu_t} \sum_{t=0}^{\infty} (1+\rho)^{-t} N_t \frac{\left(\frac{C_t}{N_t}\right)^{\tau-1}}{\tau - 1} \,. \tag{23}$$

In problem (23), ρ represents the rate of time preference, and τ is a measure of relative risk aversion with respect to period consumption. Consumption, C_t, is one control variable, and is constrained by the limitations on output built into equations (11) through (22), and the fact that consumption over time can not exceed total output. Although it does not appear in problem (23), there is a second control variable implicit in the model: limitations on GHG emissions, represented above by the variable μ_t. Recall that μ_t appeared in equations (12) and (16). We assume that government policy can influence not only μ_t but also, through a variety of policies designed to influence saving patterns, C_t. The computer model does not maximize utility, but it does show the utility associated with each policy.

Deriving Cost Parameters

Deriving the parameter values for my model is not easy, since the total effect must be spread between both total and incremental change. In order to find values for the parameters D_1 and D_2, I run a least squares regression on a number of estimates of losses resulting from climate change, using the following model:

$$G_i = D_1 x_{1i} + D_2 x_{2i}^2 + \varepsilon_i \,. \tag{24}$$

In equation (24), G_i represents the estimate of total losses, measured in percent of Gross World Product (GWP), that different economists have predicted for different amounts of climate change. I make the assumption that the rise in temperature will follow a linear path, a combination of an exponential rise in carbon concentrations due to increased output, and a logarithmic rise in temperatures in response to carbon concentrations. For each estimate *i*, then, I set x_{1i} as the average annual temperature increase, and x_{2i} as the total temperature increase. My data come from Bruce et al. (1996. 203). The five estimates used are the most recent by Cline, Fankhauser, Nordhaus, Titus, and Tol, (Bruce et al. 1996, 203). The values I receive are 0.002510 for D_1 and 0.0008535 for D_2. The standard error on the latter estimate is 0.00085. If my hypothesis is that D_2 is zero, then I have certainly not proved otherwise on the basis of our comparison of five estimates of future damages. If, however, I believe that D_2 is not zero, but is some positive number, then the possible value could be quite a bit higher than the median estimate. Finally, to check the legitimacy of my method, we run a second regression in which D_2 was constrained to zero; I arrived at an estimate for D_1 of 0.0052. Note that this parameter estimate is only slightly larger than Nordhaus' estimate of 0.0043. This may be accounted for by the use of the more recent assessments in the IPCC 1995 report, which were not available to Nordhaus. Peck and Teisberg (1993a) show that the predicted damage costs may be more sensitive to non-linearity than to coefficient parameters. Thus it may be more fruitful to model different estimates for the exponent on T^2_t, which I have assumed to be 2, than the values for D_1 and D_2. I have not taken this into account, and do not model different values for the exponent.

As with damage costs, my model differs from that used by Nordhaus in that I consider not only the total amount of control but also the rate of control as being determinative. This reflects a belief that a path of emissions control that is slow and steady will be less expensive than one that is either sudden or erratic. This follows the approach used by Grubb (1995). In order to derive values for b_1 and b_2, I run a least squares regression on past estimates of damage costs.

$$H_i = b_1 p_{1i} + b_2 p_{2i}^{2.887} + \varepsilon_i \,. \tag{25}$$

H_i is the estimated total cost of control instituted. I take p_{2i} as the total amount of control taken and p_{1i} as the average incremental control, assuming linear implementation of control measures over time. My data come from Bruce et al. (1996, 304). I rely on seventy-two estimates of control costs, each assuming a different levels of control (ranging from 5% to 96% reduction) by a different date (ranging from 2,000 to 2,100). All of the estimates were made between 1990 and 1992. The values I arrive at are 0.05758 for b_1 and 0.004509 for b_2. Again, the estimate for b_2 is not significantly different from zero, having a standard error of 0.1739; using this form of estimation, we would not be able to show that b_2 is positive. However, my null hypothesis is that b_2 is greater than zero, and because of its large standard error could be quite a bit higher than my median estimate. As with damage costs, I compare my results with Nordhaus by constraining b_2 to be zero. Doing so, I estimate b_1 at 0.05769. Nordhaus' median estimate for b_1, assuming of course b_2 to be zero, was 0.0690, which is reasonably close to my estimate.

Additional Parameter Values

The values for additional parameters are given in Table 1. They are taken from Nordhaus (1994a) and Pizer (1996).

Table 1

Parameter	symbol	value
rate of time preference	ρ	0.030000
relative risk aversion	τ	1.221300
output capital elasticity	θ	0.376400
initial productivity growth	γ_a	0.013000
rate of capital depreciation	δ_k	0.045000
decline in population growth	δ_n	0.019500
decline in productivity growth	δ_a	0.011000
retention coefficient for CO_2	β	0.640000
temperature sensitivity for CO_2	λ	0.714293
initial intensity growth	γ_σ	-0.011700
decay rate of CO_2	δ_m	0.008330
atmospheric thermal capacity	$1/R_1$	0.048000
ocean thermal capacity	$1/R_2$	0.004545
air–ocean thermal conductivity	τ_{12}	0.440000
1995 population (millions)	N_0	5590.000000
1995 population growth	γ_n	0.012400
1995 CO_2 economic intensity	σ_0	0.385000
1995 capital stock ($trillion US)	K_0	79.500000
1995 GHG concentration (GtC)	M_0	763.600000
1995 excess air temperature (•C)	T_0	0.763000
1995 excess ocean temp. (•C)	T^*_0	0.117000
1995 productivity of labor	A_0	0.009630
1995 global output ($trillion US)	Y_0	24.000000
total abatement coefficient	b_1	0.057580
marginal abatement coefficient	b_2	0.004509
total abatement exponent	b_3	2.887000
total temperature coefficient	D_1	0.002510
marginal temperature coefficient	D_2	0.000854

References

Anderson, Philip, Kenneth Arrow, and David Pines (eds.) 1988. *The Economy as an Evolving Complex System, Volume V, Santa Fe Institute Studies in the Sciences of Complexity*. Redwood City: Addison-Wesley Publishing Company.

Arrow, K.J., W.R. Cline, K-G. Maler, M. Munasinghe, R. Squitieri, and J.E. Stiglitz 1996. Intertemporal equity, discounting, and economic efficiency. In *Climate Change 1995: Economic and Social Dimensions: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, ed. J. Bruce, H. Lee, and E. Haites, pp. 125-144. Cambridge: Cambridge University Press.

Arrow, K.J. and M. Kurz 1970. *Public Investment, the Rate of Return and Optimal Fiscal Policy*. Baltimore: Johns Hopkins University Press.

Arthur, W. Brian 1988. Self-reinforcing mechanisms in economics. In *The Economy as an Evolving Complex System*, ed. P. Anderson, K. Arrow, and D. Pines, pp. 9-32. Redwood City: Addison-Wesley Publishing Company.

Ausubel, Jesse H. (1995). Technical progress and climatic change. *Energy Policy* **23** (4/5): 411-16.

Boholm, Åsa (1996). Risk perception and social anthropology: critique of cultural theory. *Ethnos* **61** (1/2): 64-84.

Bruce, James P., Hoesung Lee, and Erik F. Haites (eds.) 1996. *Climate Change 1995: Economic and Social Dimensions: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Cline, William R. 1992. *The Economics of Global Warming*. Washington DC: Institute for International Economics.

Cline, William R. 1993. Greenhouse policy after Rio: economics, science, and politics." In *Costs, Impacts, and Benefits of CO_2 Mitigation*, ed. Y. Kaya, N Nakicenovic, W. Nordhaus, and F. Toth, pp. 41-56. Laxenburg: International Institute for Applied Systems Analysis.

Dean, Andrew 1994. Costs of cutting CO_2 emissions: evidence from 'top-down' models. In *The Economics of Climate Change, Proceeding of an OECD/IEA Conference*, pp. 25-42. Paris: OECD.

Dornbusch, Rudiger and James Poterba (eds.) 1990. *Global Warming: Economic Policy Responses*. Cambridge: MIT Press.

Douglas, Mary 1998. Human needs and wants. In *Human Choice and Climate Change: An International Assessment, Volume 1*, ed. S. Rayner and E. Malone, pp. 193-262. Washington DC: Battelle Press (in press).

Douglas, Mary 1978. Cultural bias. Royal Anthropological Institute Occasional Paper No. 35. London: Royal Anthropological Institute.

Dowlatabadi, Hadi 1995. Integrated assessment models of climate change: an incomplete overview. *Energy Policy* **23** (4/5): 289-96.

Goldemberg, J., T. Johansson, A. Reddy, and R. Williams 1988. *Energy for a Sustainable World*. New Delhi: Wiley Eastern.

Grubb, Michael 1995. The economics of changing course: implications of adaptability and inertia for optimal climate policy. *Energy Policy* **23** (4/5): 417-31.

Hope, Chris and Philip Maul 1996. Valuing the impact of CO_2 emissions. *Energy Policy* **24**(3): 211-19.

Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.) 1996. *Climate Change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Hourcade, Jean-Charles and T. Chapuis 1993. No regrets potentials and technical innovation: A viability approach to integrative assessment of climate policies. In *Integrative Assessments of Mitigation Impacts and Adaptation to Climate Change*, ed. N. Nakicenovic, W.D. Nordhaus, and R. Richels, pp. 535–558. Laxenburg: International Institute for Applied Systems Analysis.

Irwin, Alan and Brian Wynne (eds.) 1996. *Misunderstanding Science? The Public Reconstruction of Science and Technology*. Cambridge: Cambridge University Press.

Jaeger, Carlo C. 1998. Decision analysis and rational action." In *Human Choice and Climate Change: An International Assessment, Volume 3,* ed. S. Rayner and E. Malone, pp. 143-216. Washington DC: Battelle Press (in press).

Kahneman, Daniel and Amos Tversky 1979. Prospect theory: an analysis of decision under Risk. *Econometrica* **47**: 263-291.

Kauffman, Robert 1997. Assessing the DICE model: uncertainty associated with the emission and retention of greenhouse gases. *Climatic Change* **35**(4): 435-448.

Kaya, Y., N Nakicenovic, W. Nordhaus, and F. Toth (eds.) 1993. *Costs, Impacts, and Benefits of CO_2 Mitigation*. Proceedings of a Workshop held on 28-30 September 1992 at IIASA. Laxenburg: International Institute for Applied Systems Analysis.

Kolstad, Charles D. 1993. Looking vs. leaping: the timing of CO_2 control in the face of uncertainty and learning. In *Costs, Impacts, and Benefits of CO_2 Mitigation,* ed. Y. Kaya, N Nakicenovic, W. Nordhaus, and F. Toth, pp. 63-82. Laxenburg: International Institute for Applied Systems Analysis.

Koopmans, T.C. 1960. Stationary ordinal utility and impatience. *Econometrica* **28**: 287-309.

Lave, Lester 1990. Comments: tax policy to combat global warming." In *Global Warming: Economic Policy Responses*, ed. R. Dornbusch and J. Poterba, pp. 98-104. Cambridge: MIT Press.

Lind, Robert C. 1995. Intergenerational equity, discounting, and the role of cost-benefit analysis in evaluating global climate policy. *Energy Policy* **23** (4/5): 379-89.

Ludwig, Donald, Ray Hilborn, and Carl Walters 1993. Uncertainty, resource exploitation, and conservation: lessons from hHistory. *Science* **260**: 17, 36.

Maddison, David 1995. A cost-benefit analysis of slowing climate change. *Energy Policy* **23** (4/5): 337-46.

Manne, Alan S. 1995. The rate of time preference: implications for the greenhouse debate. *Energy Policy* **23** (4/5): 391-94.

Manne, Alan S. and Richard G. Richels 1991. Buying greenhouse insurance. *Energy Policy* **19**: 543-52.

Mendelsohn, Robert and J. Neumann (eds.) 1998. *The Impacts of Climate Change on the American Economy*. Cambridge: Cambridge University Press (in press).

Mendelsohn, Robert, Wendy Morrison, Michael Schlesinger, and Natlia Andronova 1997. Country-specific market impacts of climate change. University of Illinois Urbana-Champagne Working Paper.

Mintzer, Irving 1987. *A Matter of Degrees*. Washington DC: World Resources Institute.

Munasinghe, M., P. Meier, M. Hoel, S.W. Hong, and A. Aaheim 1996. Applicability of techniques of cost-benefit analysis to climate change. In *Climate Change 1995: Economic and Social Dimensions: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change,* ed. J. Bruce, H. Lee, and E. Haites, pp. 145-178. Cambridge: Cambridge University Press.

Nakicenovic, N., W.D. Nordhaus, and R. Richels 1993. *Integrative Assessments of Mitigation Impacts and Adaptation to Climate Change.* Laxenburg: International Institute for Applied Systems Analysis.

Nordhaus, William D. 1991a. The costs of slowing climate change: a survey. *Energy Journal* **12**: 37-65.

Nordhaus, William D. 1991b. To slow or not to slow: the economics of the greenhouse effect. *Economic Journal* **101**: 920-937.

Nordhaus, William D. 1992. An optimal transition path for controlling greenhouse gases. *Science* **258**: 1315-19.

Nordhaus, William D. 1993a. Optimal Greenhouse-Gas Reductions and Tax Policy in the 'DICE' Model. *American Economic Association Papers and Proceedings* **83**(2): 313-17.

Nordhaus, William D. 1993b. The economics of greenhouse warming: what are the issues? In *Costs, Impacts, and Benefits of CO_2 Mitigation,* ed. *Y.* Kaya, N Nakicenovic, W. Nordhaus, and F. Toth, pp. 31-40. Laxenburg: International Institute for Applied Systems Analysis.

Nordhaus, William D. 1994a. *Managing the Global Commons*. Cambridge: MIT Press.

Nordhaus, William D. 1994b. Expert opinion on climate change. *American Scientist* **80**: 45-51.

Okun, Arthur 1975. *Equality and Efficiency: The Big Tradeoff*. Washington DC: Brookings Institute.

Organization for Economic Cooperation and Development 1994. *The Economics of Climate Change, Proceeding of an OECD/IEA Conference*. Paris: OECD.

Patt, Anthony G. 1997. Assessing extreme outcomes: the strategic treatment of low probability outcomes of climate change. ENRP Discussion Paper E-97-10, Kennedy School of Government, Harvard University, June 1997.

Pearce D.W., W.R. Cline, A.N. Achanta, S. Fankhauser, R.K. Pachauri, R.S.J. Tol, and P. Vellinga 1996. The social costs of climate change: greenhouse damage and the benefits of control In *Climate Change 1995: Economic and Social Dimensions: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change,* ed. J. Bruce, H. Lee, and E. Haites, pp. 179-224. Cambridge: Cambridge University Press.

Peck, Stephen and Thomas Teisberg 1993a. The importance of nonlinearities in global warming damage costs. In *Assessing Surprises and Nonlinearities in Greenhouse Warming: Proceedings of an Interdisciplinary Workshop,* ed. J. Darmstadter and M. Toman, pp. 90-108. Washington DC: Resources for the Future.

Peck, Stephen and Thomas Teisberg 1993b. Summary of global warming uncertainties and the value of information: an analysis using CETA. In *Costs, Impacts, and Benefits of CO_2 Mitigation,* ed. *Y.* Kaya, Y., N Nakicenovic, W. Nordhaus, and F. Toth, pp. 57-62. Laxenburg: International Institute for Applied Systems Analysis.

Peck, Stephen and Thomas Teisberg 1995. International CO_2 emissions control: an analysis using CETA," *Energy Policy* **23** (4/5): 297-308.

Pizer, William A. 1996. Modeling long-term policy under uncertainty. Ph.D. Thesis, Harvard University.

Ravetz, J. R. 1990. *The Merger of Knowledge with Power: Essays in Critical Science*. London: Mansell Publishing Limited.

Rayner, Steve 1995. *Governance and the Global Commons*. Discussion Paper 8, The Centre for the Study of Global Governance, London School of Economics.

Rayner, Steve and Elizabeth Malone (eds.) 1998. *Human Choice and Climate Change: An International Assessment, Volume 1, The Societal Framework of Climate Change.* Washington DC: Battelle Press (in press).

Rayner, Steve and Elizabeth Malone (eds.) 1998. *Human Choice and Climate Change: An International Assessment, Volume 3, The Tools for Policy Analysis*. Washington DC: Battelle Press (in press).

Repetto, Robert and Duncan Austin 1997. *The Costs of Climate Protection: A guide for the Perplexed.* Washington DC: Worldwatch Institute.

Roe, E.M. 1996. Sustainable development and cultural theory. *International Journal of Sustainable Development and World Ecology* **3**: 1-14.

Schelling, Thomas C. 1995. Intergenerational Discounting. *Energy Policy* **23** (4/5): 395-402.

Schwarz, Michiel and Michael Thompson 1990. *Divided We Stand: Redefining Politics, Technology, and Social Choice.* Philadelphia: University of Pennsylvania Press.

Stokey, Edith and Richard Zeckhauser 1978. *A Primer for Policy Analysis*. Cambridge: Harvard University Press.

Thompson, Michael and Steve Rayner 1998. Cultural discourses. In *Human Choice and Climate Change: An International Assessment, Volume 1,* ed. S. Rayner and E. Malone, pp. 263-382. Washington DC: Battelle Press (in press).

Tietenberg, Thomas 1988. *Environmental and Natural Resource Economics, second edition*. Glenview: Scott Foresman & Co.

Van der Sluijs, Jeroen, Josee van Eijnhoven, Brian Wynne, and Simon Shackley 1997. Anchoring devices in science for policy: the case of consensus around climate sensitivity. *Social Studies of Science*, Spring 1997.

Toth, Ferenc L. 1995. Discounting in integrated assessments of climate change. *Energy Policy* **23** (4/5): 403-09.

Walters, Carl 1987. *Adaptive Management of Renewable Resources.* Cambridge: Cambridge University Press.

White House Conference on Science and Economics Research Related to Global Change 1990. *Delegate Information Book.* Washington DC, April 17-18.

Wynne, Brian 1996. Misunderstood Misunderstandings: Social Identities and the Public Uptake of Science. In *Misunderstanding Science? The Public Reconstruction of Science and Technology,* ed. A. Irwin and B. Wynne, pp. 19-40. Cambridge: Cambridge University Press.

Yohe, Gary and Robin Cantor 1998. Economic activity and analysis. In *Human Choice and Climate Change: An International Assessment, Volume 3,* ed. S. Rayner and E. Malone, pp. 1-106. Washington DC: Battelle Press (in press).