The Climate for Greenhouse Policy in the U.S. and the Incorporation of Uncertainties into Integrated Assessments

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The climate policy situation in the United States is complex, influenced by a shifting mix of cost/benefit analyses, technology development studies, environmental advocates, fossil fuel industry lobbyists, and vocal ideological opponents of taxation and governmental controls.

Political Situation. Although the U.S. has been at the forefront of environmental regulations and the development of pollution control technologies for three decades, environmental policies have been most politically effective when human health has been perceived to be threatened (e.g., with toxic waste regulations, air pollution control standards and CFC restraints to reduce stratospheric ozone depletion – perceived as a skin cancer risk). Furthermore, since the Reagan administration, the political climate has been marked by rhetoric promoting suspicions of governmental intrusion into individual or business entrepreneurial ventures. Such rhetoric includes attacks on environmental "over regulation" and taxation in general. Despite the Clinton-Gore election in 1992 – pushing the political pendulum back towards some respectability for policies aimed at protecting the global commons (including the climate, Vice President Al Gore's long-standing passion, e.g. Gore, 1992) -- the advent of conservative Republican majorities in both the Senate and the House of Representatives in 1994 reinforced old ideological opposition to governmental actions to protect commons resources. Opposition has been particularly vocal if the protection measures proposed implied loss of jobs in well organized industries like coal mining or implied constraints on so-called "free-market" entrepreneurs or involved actions perceived by such entrepreneurs or their advocates (e.g. editors of the Wall Street Journal) as conferring competitive advantage to foreign interests. The latter perception led to a ten million dollar advertising campaign in the media by fossil fuel industry interests to first sabotage, and later oppose, ratification of the Kyoto protocol on global warming. The ads were built on the ostensible grounds that the treaty wouldn't work and would unfairly export American jobs overseas because of developing countries' exemption from binding emissions reductions targets. The U.S. Senate in 1997 passed 95-0 a non-binding resolution urging the President not to enter into any agreement at Kyoto in which any country was exempted from constraints – and since the Senate must ratify any treaties the administration signs, such a threat from the Senate put pressures on the Clinton negotiators, who in turn applied pressures at Kyoto to include joint implementation, international carbon trading schemes and at least voluntary participation of less developed countries (LDCs).

One of the claims of the industry ad campaign was that climate control actions would damage U.S. economic growth and create massive domestic unemployment while exporting jobs overseas. The justification for this fear tactic was an economic model cost/benefit study performed by a private company, The Charles River Associates. This study assumed a $200/ton carbon tax applied without warning to the economy. Let us turn, then to cost-effectiveness studies, which are very prevalent in the U.S.

Cost-Effectiveness Not surprisingly, the industry ads neglected to mention that the vast majority of cost/benefit studies performed in the U.S. calculated optimal carbon taxes ranging from a few dollars per ton of carbon to a few tens of dollars initially, ramping up slowly over time (e.g., Nordhaus, 1992; Manne and Richels, 1992, Gaskins and Weyant, 1993). The costs to the economy of climate abatement policies typically range from a net benefit (when pre-existing market failures are assumed, e.g., NAS, 1991) to a percent or so of GDP lost – below the recent growth rate of that common measure of economic well-being. Wigley, Richels and Edmonds (1996) (hereafter WRE), argued that it is most cost effective to delay the bulk of carbon abatement into the future (so called “when flexibility”) in order to wait for technological developments in low-carbon energy technologies that lower their costs.

Many U.S. economists (e.g. Manne and Richels, 1997) have argued that it is often cheaper to abate carbon in LDCs than DCs (so called “where flexibility”). Both “where” and “when” flexibility are designed to lower total costs of abatement and have become important factors in internal U.S. climate policy discussions and in U.S. negotiating positions.

WRE have often been improperly cited as advocating delay in climate policy, which they do not advocate. As Schneider and Goulder (1997) (hereafter SG) pointed out, cost effective carbon abatement policies may well imply delay in the timing of *abatement*, but that to bring about the lower cost alternative technologies which can more cost effectively be substituted for current high-carbon energy systems requires strong and immediate *policies* to create incentives to induce technological change (ITC). SG argued that carbon taxes are probably a much more economically efficient means to abate a unit of carbon emissions relative to (the politically more palatable) policy of direct technology development subsidies – except when certain pre-existing market distortions are present, in which case a combination of carbon taxes and research and development (R&D) subsidies are most efficient. Both WRE and SG also noted that they were calculating cost-effectiveness of abatement policies, not “optimal” climate policies since only the cost side was considered in those studies and the benefits of abatement (so-called “avoided climate damages”) were not explicitly considered. Climate damage has, of course, been explicitly considered in optimal policy, cost/benefit studies such as the dynamic integrated climate economy (DICE) model by Nordhaus (1992). Let’s examine further this pioneering integrated assessment model (IAM), since IAMs are quite integral to the analytic contribution to the climate policy debate in the U.S.

Integrated Assessment There are several IAMs which have been used for the analysis of emission control policies. These models vary in complexity, structure, and the numerical values of key parameters. Indeed, no IA model can credibly deal with all important factors nor cover the wide range of value-laden alternatives that need to be considered in real-world policy-making (e.g., see the reviews by Morgan and Dowlatabadi, 1996, and Schneider, 1997). Nevertheless, IAMs can provide insights via sensitivity analyses of key uncertain parameters, structural elements, and value choices. The DICE model is a well known, well documented and relatively simple IAM. The transparency of the model allows for several reformulations and extensions to alternative assumptions (e.g., Chapman et al., 1995, Kaufmann, 1997). Although the simplicity of this approach precludes taking the quantitative results literally, the qualitative insights have hopefully proven useful to the climate policy-making community.

The DICE model was originally designed to compare the economic effects of several different policies regarding the control of anthropogenic carbon dioxide emissions. One such policy is "Business-As-Usual" (BAU) or baseline scenario, where no efforts are made to control greenhouse gas emissions (e.g., IPCC 1996a). In this "no controls" scenario, there is no emissions abatement (and thus no abatement costs), but we might expect the temperature increase, and hence the potential damage from climatic change, both to be higher.

In the "optimal" policy scenario, the "no-controls" constraint is relaxed, and the control rate is determined endogenously. In this scenario, DICE is free to trade off the costs of climatic change with those of emissions abatement. If the costs of global warming are relatively small, the incentive to mitigate carbon emissions will also be small (i.e., the BAU scenario would be close to the optimal one). If the impacts of climatic change are great, however, we would expect the control rate to be large, implying that "Business-As-Usual" would be a relatively poor policy, from the point of view of optimizing economic efficiency including the climate damage externality.

Discounted consumption is used by Nordhaus as the primary criterion for comparing different model results. "Discounted consumption" here refers to all consumption occurring after 1989, discounted to 1990 by the rate of interest on goods and services calculated in the standard optimal DICE run. Since utility is an increasing function of consumption, in this formulation larger quantities of discounted consumption are taken as more desirable. (I will not debate here the various challenges to the utility maximizing paradigm, such as the "precautionary principle", "stewardship", "equity" and other competitive policy principles -- see, e.g, Jenkins, 1996 and Brown, 1997 -- since the cost/benefit paradigm is still dominant in U.S. policy analysis debates).

<u>Quantifying Climate Damage Uncertainties</u> There are currently many different estimates and countless opinions regarding the economic impacts of global warming. The DICE model includes a climate damage function based on Nordhaus' personal estimate. Roughgarden and Schneider (1998) (hereafter RS) compared this function with those of several other damage estimation studies, and later added in the opinions of eighteen experts surveyed by Nordhaus (1994) in a subsequent study. These various damage function estimates radically alter the optimal carbon tax recommended by DICE, and will likely focus debate in the U.S. -- and probably elsewhere-- over the next several years about the large uncertainties inherent in climate damages. Table 1 presents an overview of recent damage estimates for a doubling of CO_2 levels by Cline (1992), Fankhauser (1995), Titus (1992), and Tol (1995). Detailed breakdowns of these estimates have been published by the IPCC (1996b). However, these values only consider damage to the United States,

and only describe a damage function for a single temperature increase value (see RS for details on how these damage functions were incorporated into DICE).

The relative character of all five damage functions is shown in Figure 1a. The functions spread out considerably with more than 3°C of warming. The function used in the original DICE model is the most conservative of the five.

Figure 1b presents the loss of discounted consumption due to climate damage in the BAU policy scenario, where no action is taken to mitigate the buildup of atmospheric greenhouse gases. These curves also represent the gross benefit of complete climatic change abatement associated with each damage function in the DICE model (since complete abatement would reduce the damage from climatic change to zero). Since a relatively large amount of climate-induced damage results in less income, and hence less consumption, the more severe damage functions result in greater losses of discounted consumption, and hence a larger economic incentive for climatic change abatement.

We next consider the "optimal" policy scenario (i.e., we remove the "no-controls" constraint), in order to compare the levels of optimal emission control rates (the level of mitigation) and optimal carbon taxes (the mechanism used to induce the mitigation) for each of the damage estimates. Figure 1c shows the values of the optimal carbon taxes associated with each damage function (on Fig 1a).

With the original damage function, the DICE model calculates modest carbon taxes -- less than 10 1990 U.S. dollars per ton of carbon over the next two decades, with a tax of just over $20 by the end of the 21st century. By contrast, these numbers double when the DICE model is run with the damage estimates of Fankhauser or Tol. Similarly, the optimal emission control rates for model runs with Fankhauser or Tol damage estimates are over 50% higher than those in the canonical DICE run.

A second source for estimates of damage from climatic change is an expert survey conducted by Nordhaus (1994). Nineteen experts from the natural sciences, the social sciences, technology, and economics were questioned about the economic impacts, distributional effects, and non-market effects of global warming. For all questions, three scenarios were considered: a 3°C warming by 2090 (scenario A); a 6°C warming by 2175 (scenario B); and a 6°C warming by 2090 (scenario C). RS concentrated on the experts' opinions regarding economic impacts in scenarios A and C.

The survey respondents were categorized by Nordhaus as natural scientists, environmental economists, and "other social scientists" (a group composed primarily of "mainstream" economists). There is considerable variation in opinion between researchers of these different fields. The natural scientists' average damage estimate is far more pessimistic for the world economy than that of the social scientists, and the environmental economists average was an estimate between the other two.

In Nordhaus' survey, each respondent gives low (10th percentile), median or "best guess" (50th percentile), and high (90th percentile) estimates for damage in each scenario. The bulk of the (both optimistic and pessimistic) experts thought that their best guess for climatic damage had a greater chance of being a large underestimate than a large overestimate; in other terms, a higher probability of a "nasty surprise" than a "pleasant surprise" (e.g., see Schneider, Turner, and Morehouse Garriga, 1998 for discussions on the surprise issue). Given the skewness of the data, RS fit a Weibull distribution to the damage estimates of each survey respondent, which is reproduced here in Figure 2. The cumulative distribution functions (CDFs) for damage in scenarios A and C are given in Figure 2a and the probability density functions (PDFs) in Figure 2b.

A striking feature of both distributions is their right-skewness (i.e., "surprise potential"). For the 3°C warming scenario, the mode of the distribution (the peak of the PDF) is very close to zero, indicating that for the surveyed experts the potential benefits of climatic change (e.g. longer growing seasons, CO_2-enhanced photosynthesis, etc.) are believed likely to offset most of the damages. Looking at the CDF, however, we see that there is a significant (>10%) chance of a loss of more than 10% of the gross world product in this scenario. For scenario C, the shape of the distribution is similar. According to the aggregated expert opinion, there is a 50% chance of experiencing less than 6% GWP loss from 6°C of warming, but a 4% chance that the climatic change in this scenario will cut global output in half - an unimaginable economic catastrophe! Five damage functions derived from random samples of the damage distributions are presented in Figure 2c, from the 1st, 10th, 50th, 90th, and 99th percentile damage estimates.

Roughgarden and Schneider (1998) also performed a probabilistic analysis with the expert opinions from Nordhaus' survey. In a Monte Carlo calculation, each of one thousand runs selects random input parameters, drawn from the previously derived damage distributions, reformulates the DICE model with a damage function derived from this random selection, and runs the new model to generate data for a distribution of optimal scenarios. This exercise is useful for displaying quantitatively the effects of the uncertainty of the economic costs of climatic change on the output of this IAM.

We have already seen that the damage distributions derived from the aforementioned expert survey have large variances in the magnitude of damage from unmitigated climatic change. RS further considered the distribution of optimal policy, in the form of carbon taxes, associated with these damage distributions. Using the results of the Monte Carlo simulation, distributions for optimal carbon taxes in the years 1995, 2055, and 2105 were derived.

All optimal carbon tax distributions suggest a non-negligible probability that a large carbon tax is needed for optimal response to potential climatic change (for example, see Table 2). One quarter of the simulation runs "recommend" a 1995 carbon tax of at least $50 per ton of carbon, which is a tenfold increase from the optimal tax in the canonical run. About 15% of the runs give similarly enhanced tax levels for 2055 and 2105. In the most pessimistic damage runs, optimal carbon taxes start at nearly $200 per ton in 1995, and climb to nearly $500 per ton by the end of the 21st century. At the same time, the optimal distributions suggested about a 10% chance that carbon taxes should be negative (i.e., carbon emissions should enjoy a subsidy).

<u>Climate Damages or Benefits?</u> These very large (even if they carry a low subjective probability) damage cases are often labeled "surprise scenarios", and have been a major consideration in the U.S. climate debate from both a scientific (e.g. Broecker, 1997) and business perspectives. For example, the U.S. reinsurance industry fears it is already a victim of climate change and calls for both emissions controls and insurance rate increases. Frank Nutter, president of the Reinsurance Association of America, told Time Magazine ("Burned By Warming," Time Magazine, 14 March 1994, p. 79): "The insurance business is first in line to be affected by climate change...it could bankrupt the industry."

However, also prominent in the U.S. climate damage debate is a strong emphasis on hypothesized benefits of CO2-enhanced photosynthesis and associated improved water use efficiency in crops and forests (e.g., see Lave and Shevliakova, this issue). Based on extrapolation of field and lab experiments with single plants to whole ecosystems (a dubious proposition to many ecologists -- see the references in Root and Schneider, 1995) some economists (e.g., Mendelsohn, Nordhaus, and Shaw, 1996) have used the so called "hedonic method" to calculate climate impacts from increased temperature and direct CO_2 effects. The broad generalization from several such studies is that currently cold climates will see net market sector benefits and currently hot climates net market sector losses. Mendelsohn and colleagues readily admit they haven't treated non-market damages like biodiversity losses or potential for interstate conflicts from displaced populations that lost a favored climate (but non-market losses <u>are</u> estimated by the Nordhaus (1994) survey respondents). These analysts using the hedonic methods nevertheless claim that the U.S. is likely to receive net economic benefits in market sectors for climate change scenarios with temperature increases less than 5°C. I (Schneider, 1997) have criticized use of hedonic methods in this application on three grounds: a) they assume that variations over time at one place can be quantitatively evaluated by examining current differences in managed and unmanaged ecosystems from place to place; b) that transient changes can be neglected, and c) that higher moments of climate change (e.g. variances or seasonal cycle amplitude changes) can safely be neglected. Schneider (1997) labels this kind of analysis "ergodic economics," and argues that the above three assumptions are sufficiently problematic as to render most quantitative conclusions from hedonic methods applied to climate impacts analysis as highly speculative -- thus I prefer the Nordhaus survey approach in which results based on hedonic methods are essentially anticipated by the left-hand portion of the subjective probability distributions on Figure 3.

Despite these problems with methods, the possibility of optimistic climatic impact studies is frequently cited in the business press and in Congress as a reason not to embrace climate policies now (e.g. Niskanen, 1997). Similarly, the potential for nasty climate or ecological surprises are cited by environmental advocates as reasons to embrace strong emissions controls immediately (Leggett, 1990). Somewhat orthogonal to this climate damage impact assessment debate is another strand to the climate policy web: whether technology subsidies should be the focus of our actions.

<u>Induced Technological Change</u> The IPCC (1996a) analysis of the BAU emissions scenario concluded that in order to prevent a doubling or tripling of atmospheric CO_2 concentrations in the late 21st century, that at least half to three quarters of the expected emissions of fossil fuel based CO_2 emissions will need to be replaced by 2050 and beyond (see also Azar and Rodhe, 1997). That means that major research, development and deployment programs for less carbon emitting technologies need to be put into place in the decades ahead. There is considerable dispute as to how costly such programs might be, with some technical optimists asserting it can be done at *below* the costs of today's technologies because new high-tech solutions will prove cheaper (e.g., von Weizsäcker, Lovins & Lovins, 1997; Lovins & Lovins, 1997). Other analysts, however, are convinced CO_2 abatement will cost the world economies a percent or two of their gross national products to implement (e.g., Peck and Teisberg, 1995). The Kyoto agreement, since it essentially leaves out binding reductions from the growing LDCs emissions and stabilizes

rather than reduces continuously the industrial countries' emissions, implies a long term future in which CO_2 emissions will likely double or triple (Wigley, 1998). As one prominent scientist put it, "It might take another 30 Kyotos over the next century" to prevent such large increases in CO_2 concentrations (Malakoff, 1997).

How then will technological progress be induced so that significant reductions can be obtained? A study by five U.S. Dept. of Energy Labs (DOE, 1997), suggests that the U.S. could offset some of its carbon emissions at an economic gain (i.e., investments are less than fuel savings) simply by deploying already available more energy-efficient technologies like compact fluorescent lights, infrared radiation reflecting windows, better electric motors and combined cycle gas power plants (especially with so-called co-generation opportunities). "No regrets" alternatives -- those with less than zero net costs -- have long been recommended by formal U.S. studies (e.g., NAS 1991, OTA, 1991), although it is widely acknowledged that changes in existing regulatory disincentives (e.g., Bayless & Casten, 1997) and other suboptimal management practices may need to be overcome by appropriate policies (for a small scale example, see Selmon and Schneider, 1997). On the other hand, in contrast to such "bottom-up", engineering analyses of technological potential, some economists (see the discussion in Chapter 6 of NAS, 1991) have argued that macroeconomic models (so called "top-down" analyses) demonstrate that costs hidden to energy engineers but known to business investors imply that few real "no regrets" options exist. Thus, claims by technologists that the U.S. can reduce (by tens of percent) its greenhouse gas emissions at near zero (or below zero) costs are typically viewed by such economists as unlikely. The outcome of the top-down/bottom-up debate has a large implication for what are "optimal" carbon taxes (e.g., Azar, 1996).

Another component of the technology debate in the U.S. is whether macroeconomic models like DICE have been underestimating technological progress (and thus overestimating economic costs of abatement) by assuming technological progress is only a function of time (so called "autonomous energy efficiency improvement") rather than being an endogenous response of the industrial system to price incentives when climate policy drives up the price of using carbon intense energy (e.g., Grubb et al., 1995; Goulder and Schneider, 1998). Ausubel (1995), on the other hand, has argued that the world will evolve towards a "methane economy" and then a "hydrogen economy" that will prevent even a doubling of CO_2, a technological change he believes will be an autonomous result of a "technological trajectory" now underway. Most U.S. economists are much less optimistic about the likely rate of decarbonization, and debate thus continues.

The U.S. position at Kyoto emphasized incentives to technological development, and President Clinton proposed spending $6 billion per year for this in his 1998 State of the Union Address to Congress. An internal debate in the U.S. is engaged over whether the more politically popular alternative technology subsidies approach should be emphasized rather than the more economically efficient (except when there are pre-existing market failures – see Schneider & Goulder, 1997) carbon tax (or tradable permits) strategy. Although political leaders often indulge in "efficient, free market" rhetoric, it is easier in the U.S. to legislate an inefficient subsidy than to promote real economic efficiency by internalizing external costs like climate damages into the price of energy via a carbon tax or tradable permits scheme.

Focus on Leap Frogging Mechanisms: A Personal Perspective When I spoke at formal panels and press conferences at Kyoto, I expressed reservations about *all* the main positions offered (e.g., see Schneider, 1998). I agreed that we need major and immediate steps to prevent a doubling of CO_2 by the middle to the end of next century, and that a tripling was possible if BAU development of traditional and inefficient technologies powered largely by coal and oil, continue to grow as typically predicted.

This I believe, is a major planetary risk; and I agree we probably need to replace at least half of the planned fossil fuel power use before the middle of the next century — not a very long time to accomplish a major restructuring of the energy foundations of industrial growth. I agreed with the Europeans and the environmental NGOs that immediate action is needed. I also agreed with the LDCs that their development constraints puts them in a special needs category, and that current resources are inequitably distributed, as are emissions of greenhouse gasses —the more developed countries (MDCs) being ten or more times greater per capita.

Nevertheless, I went on, "nature is indifferent to human concepts of equity. As far as the threatened ecosystems of the Earth are concerned, a ton of CO_2 emitted in Boston is equivalent to a ton emitted in Beijing. Therefore, from the perspective of preventing 'dangerous anthropogenic interference' with the climate system, all nations have to play." Delay in LDC participation in decarbonizing protocols could lock in many dozens of inefficient coal burning power plants, each with four decades of economic life in, say, India or China or Indonesia, which would not allow global warming solutions to be very cost-effective, I argued. Not unexpectedly, I got scowls from some of the Africans and Asians present. But their faces changed when I added: "But just because protecting nature and the global commons requires that all countries must *play*, fairness suggests that not all should have to *pay*!"

In other words, we need planetary-scale bargaining (like that which, I hope, will take place in post-Kyoto negotiations) to help the LDCs not merely to play faster catch-up with the industrialized world, but *to leap frog entirely the Victorian industrial revolution to a high tech, low carbon, and very efficient industrial future.* And, I believe, the MDCs should help provide technology and capital for that leapfrogging as our prime contribution to the protection of the planetary commons and in recognition of the inequities in current per capita polluting.

How best to achieve such a restructuring of the energy underpinnings of industrialized economies? To me, none of the five prime players (Europe, the U.S., the fossil fuel industry, the LDCs and the environmental NGOs) had effective proposals at Kyoto, although the US, despite its feeble targets for immediate emissions reductions, came closest. That is, the US recognized that *all must play* and that structural changes via *new and improved technologies* must be stressed. But, like nearly all the rest, the U.S. pretends they could do it without a fee for using the atmosphere as a common sewer, which appears to be the single most cost effective incentive to reduce polluting in every human activity that involves energy (e.g., Cooper, 1998). Neither the European Union, the LDCs, or the Clinton administration will utter the simple solution: "The price of carbon energy must rise to its full social cost". The administratively simplest way to do this is via a carbon tax (which, it should be noted, has been implemented by the Danish and Norwegian governments for five years, e.g., OECD, 1997). Other ways to do this include tradable permit systems, which were pushed by U.S. negotiators and partially approved at Kyoto. A system of internationally tradable carbon emissions permits would, like a carbon tax, cause the price of fossil fuels to rise, because it forces reduced use of such fuels relative to BAU (e.g., Hahn & Stavins, 1995).

How might leap frogging work? Malaysia, as an example, is considering development of an automobile industry based on Victorian technology: internal combustion engines. It is hard to imagine how it will compete economically with the similar industries of Japan, Europe and the US with a century head start — except, perhaps, via uneconomic domestic subsidies or trade barriers.

So, here's a good place to consider leapfrogging: the atmospheric sewer fee (carbon tax or quota) would make conventional engines more expensive to operate. The tax, for example, could generate enough revenue to have a portion used to subsidize MDC industries to contribute their knowledge and skills in a joint project with the Malaysians to produce the worlds first fleet of very efficient, low polluting fuel-cell-powered cars. The subsidies, having been financed from globally imposed carbon taxes, would promote the *joint participation* of industries from many countries, meaning that what is learned by actually doing the research and development in Malaysia can be shared by participating companies all around the world. Thus, this essential technological advance over conventional air-polluting cars would get a major R&D boost in an LDC that would benefit all participants and many nations.

The key is to develop the *cooperative international atmosphere* for this kind of leapfrogging consortium, and indeed, the internationally shared — and threatened — global atmosphere may provide the impetus needed to overcome the historical animosities and international competitive suspicions that typically doom such good-for-the-planet programs to media talk shows and academic seminars.

Some might be thinking that such leapfrogging is, indeed, just academic wishful thinking. Consider, then, the pattern of communications development in now-developed countries. Before extensive telephone networks could be established, tens of thousands of transmission lines and distribution exchanges were slowly installed. This infrastructure took a century to mature. China, not wishing to repeat this slow pattern of Victorian industrial development, is, with the help of international experts and investors, leapfrogging over the traditional hard-wired communications networks to high tech — cellular phones in this case. So why can't that pattern be copied in the industry with much more at stake environmentally — energy. It probably can, if governments and other relevant actors create the institutional solutions which provide incentives for such leapfrogging to flourish.

Thus, to deal with damages to the planetary commons that greenhouse emissions create, fees for dumping in those commons must be collected by the "planet" — meaning an institution that is an international surrogate for the Earth's interests does the collecting. If such an institution (e.g., see Chichilnisky, 1996, for one such suggestion) could recycle those fees into technology leapfrogging projects in LDCs and help deal with the inequities that arise due to higher energy prices, the world would then be in the position to have everybody play at the game of planetary protection, but those who are disadvantaged would not have to pay as much and could even see their long-term emissions be reduced significantly below "business-as-usual" projections made in the absence of consideration of technology leapfrogging schemes. It may be true in some circumstances that an increase in the price of conventional energy will differentially cost poorer people a larger fraction of disposable income than richer people, but it is poor economic and environmental policy to subsidize development with artificially low prices of commodities like carbon based energy, rather than with what is really needed: intellectual and financial resources for sustainable development in the 21st century. If governments act now to set up real structural changes, humanity can then be on a path towards a more sustainable future.

Summary. In the U.S. there is a rich debate over a range of climate policies among the business, academic and government analytical communities. U.S. policy circles are enamored with cost/benefit analysis via integrated assessment models, but even within that conventional analytic paradigm, uncertainties in climate effects (e.g, Morgan and Keith, 1995), climate change damages and abatement policy costs have been formally treated by statistical distributions (e.g., Fig. 3). Results suggest some ten percent subjective probability that climatic change would prove economically beneficial, a comparable likelihood of catastrophic climate surprises, and the "best guess" being a small cost to the economy from carbon policies like a modest carbon tax, tradable permit system or low carbon technology development subsidies (e.g., Roughgarden & Schneider, 1998). More problematic in the U.S. is a polarized media debate which pits "good for you" (e.g. Robinson & Robinson, 1997) versus "catastrophic" (e.g., Leggett, 1994) advocates in continuous -- and confusing -- contention. This confusion, coupled with an elliptical fossil fuel industry media campaign, organized labor union fears of lost jobs, and conservative ideological opposition to most anything "governmental" has rendered climate policy making in the U.S. problematic (e.g. Zycher, 1997), despite the many opinion polls in the U.S. suggesting the public is overwhelmingly in favor of some emissions restraints and the passions of the Vice President to satisfy that large constituency. Unfortunately, the public is also suspicious of any actions which look like new taxes, regardless of how efficient economists or industrialists or environmentalists may agree they are (for example, Hamond et al., 1997). Thus, the U.S. may well remain in climate policy gridlock for the foreseeable future -- or at least until media worthy, weather catastrophes tip the balance of public opinion decisively, even if temporarily, in favor of committing the U.S. to real emissions reductions at home and policies to encourage low carbon technological developments and transfers to LDCs.

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Table 1: A comparison of IPCC damage estimates for a CO_2-doubling scenario (damage is for U.S. only). Both temperature increase and the corresponding amount of damage are estimated. [Source: Bruce et al., 1996]

Researcher	Warming (°C)	Damage (% of GDP)
Cline	2.5	1.1
Fankhauser	2.5	1.3
Nordhaus	3.0	1.0
Titus	4.0	2.5
Tol	2.5	1.5

Table 2: Comparison of Monte Carlo simulation results with the standard DICE model. "Surprise" values are 95th percentile results.

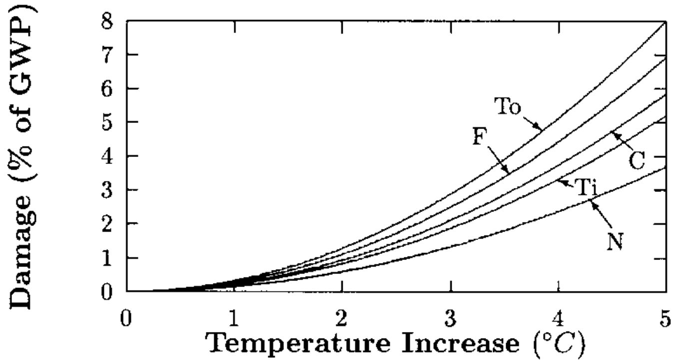
Source of	Optimal Carbon Tax ($/ton C)		
Data	1995	2055	2105
DICE	5.24	15.04	21.73
Median	22.85	51.72	66.98
Mean	40.42	84.10	109.73
"Surprise"	193.29	383.39	517.09

Figure Legends

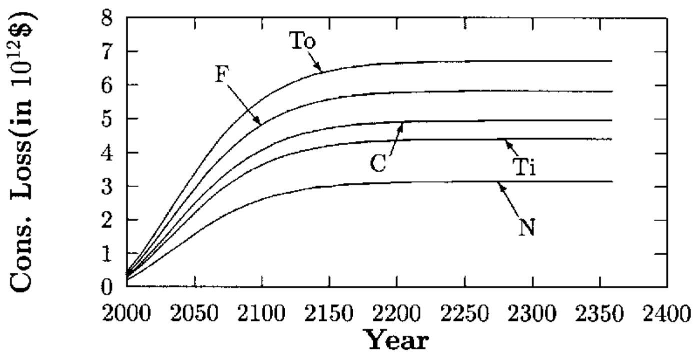
Figure 1: The DICE model reformulated with damage functions derived from damage estimates by Cline (C), Fankhauser (F), Nordhaus (N), Titus (Ti), and Tol (To). The original model used the damage function derived from Nordhaus' personal damage estimates (N). Figure 1a displays the damage functions derived from published IPCC (1996b) damage estimates. Figure 1b shows the loss of discounted consumption in the BAU scenario for each of the damage functions in Figure 1a (where discounted consumption is all consumption occurring after 1989, discounted to 1990 by the rate of interest on goods and services – 3% -- calculated in the standard optimal DICE run). In essence, these curves represent the damage of unmitigated climate change. Of course, the curves shown here represent only a small fraction of overall consumption (the largest difference between the highest and lowest curves is less than 1% of total discounted consumption). Figure 1c gives optimal carbon tax levels corresponding to each of the damage functions in Figure 1a. [Source: Roughgarden & Schneider, 1998]

Figure 2: The DICE model reformulated with damage functions derived from damage estimates given by experts. Figure 2a shows the "disciplinary damage functions" derived from an expert survey [Nordhaus, 1994], for natural scientists ("Nat. Sci."), environmental economists ("Env. Econ."), and other social scientists ("Soc. Sci."), primarily conventional economists. The original DICE damage function ("DICE '92) is also shown for comparison. In Figures 2b and 2c, optimal policy given the median damage estimates of natural scientists (x) is compared with optimal policies with the high (90th percentile) damage estimates of all of the experts ( ), the median damage estimates of all of the experts (+), and with the damage estimates used in the original DICE model (✧). Figure 2b gives optimal carbon tax levels for each group of damage estimates, and Figure 2c displays the corresponding optimal emission control rates. The increases in global average temperature by 2105 associated with these policies are 2.77°C, 2.94°C, 3.10°C, and 3.20°C, respectively, suggesting that even the largest control rate abates only a modest fraction of the projected climate changes. In addition, Figure 2c shows optimal control rates with the median damage estimates of all experts and a 1.5% social rate of time preference (Δ), half the value used for (+). [Source: Roughgarden & Schneider, 1998]

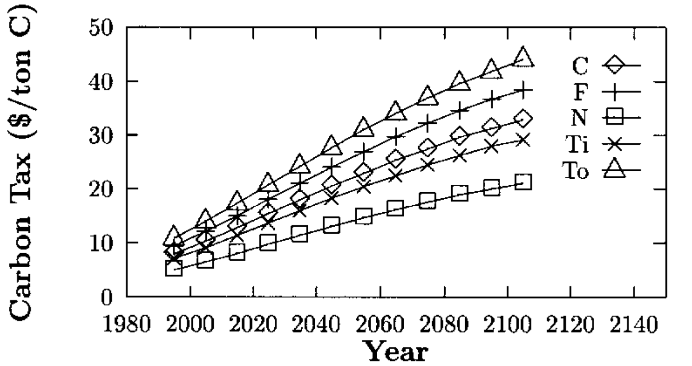
Figure 3: "Aggregate expert damage distributions" for warming scenarios A (3° by 2090) and C (6° by 2090). These distributions are used to derive randomly sampled damage functions for use in a probabilistic analysis of the DICE model under uncertainty. Figures 3a and 3b show the cumulative distribution functions and probability density functions, respectively, of the damage distributions. Figure 3c displays several example damage functions used in the Monte Carlo simulation. The "50%ile" damage function (for example) is the function through all of the following: the origin (since we assume zero damage with no temperature increase), the median of the damage distribution for scenario A at $\Delta T(t)$ = 3°C, and the median of the damage distribution for scenario C at $\Delta T(t)$ = 6°C. [Source: Roughgarden & Schneider, 1998]


Damage (% of GWP)
Temperature Increase (°C)
0
1
2
3
4
5
6
7
8
To
F
C
Ti
N

(a)


Cons. Loss(in 10^{12}\$)
Year
2000
2050
2100
2150
2200
2250
2300
2350
2400
To
F
C
Ti
N

(b)


Carbon Tax (\$/ton C)
Year
1980
2000
2020
2040
2060
2080
2100
2120
2140
0
10
20
30
40
50
C
F
N
Ti
To

(c)

Figure 1

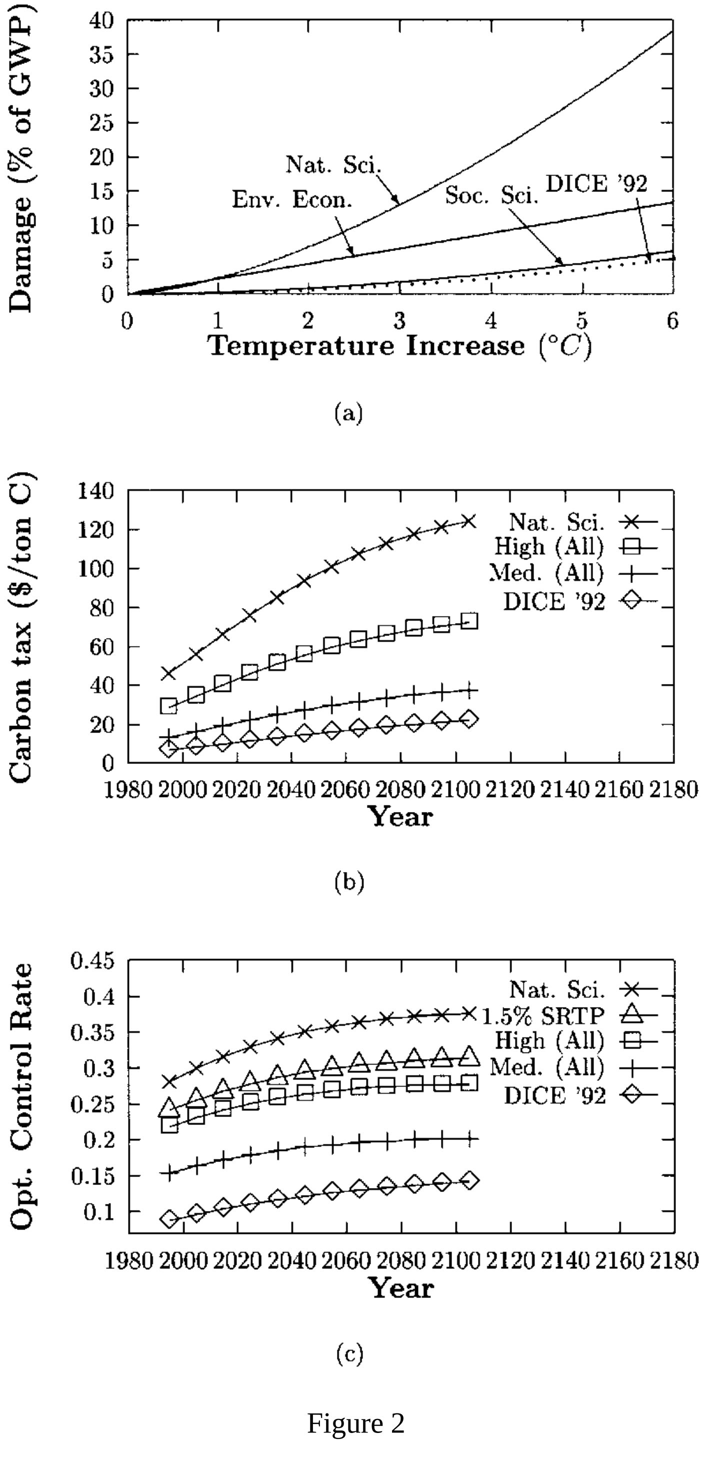
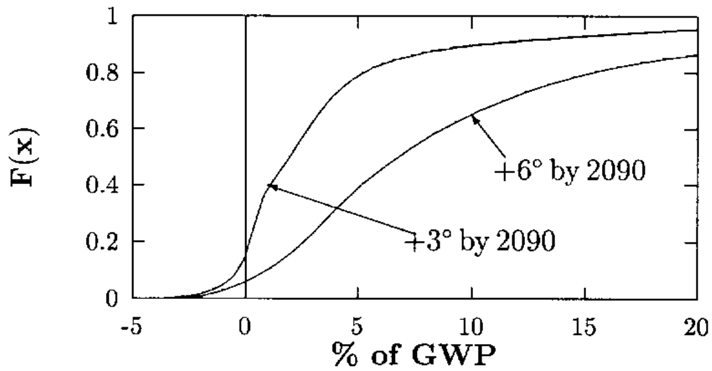
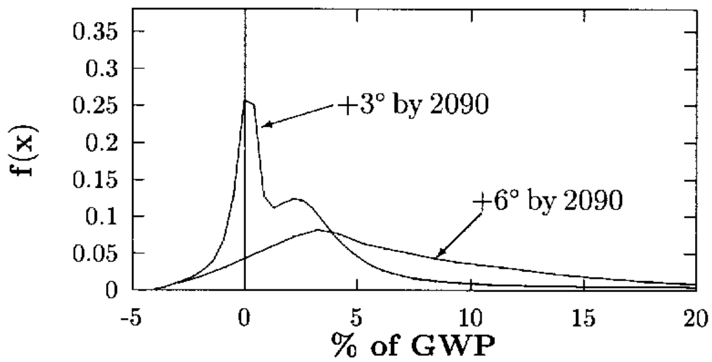

Damage (% of GWP)
Nat. Sci.
Env. Econ.
Soc. Sci.
DICE '92
Temperature Increase (°C)
(a)
Carbon tax ($/ton C)
Nat. Sci.
High (All)
Med. (All)
DICE '92
Year
(b)
Opt. Control Rate
Nat. Sci.
1.5% SRTP
High (All)
Med. (All)
DICE '92
Year
(c)

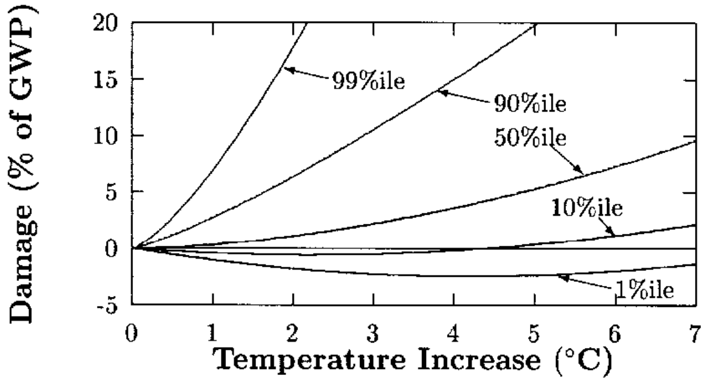
Figure 2


F(x)
% of GWP
+6° by 2090
+3° by 2090

(a)


f(x)
% of GWP
+3° by 2090
+6° by 2090

(b)


Damage (% of GWP)
Temperature Increase (°C)
99%ile
90%ile
50%ile
10%ile
1%ile

(c)

Figure 3