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Comments on EPA's Advance Notice of Public Rulemaking (ANPRM) and Technical Supporting Document (TSD) on "Regulating Greenhouse Gas Emissions under the Clean Air Act", July 30, 2008

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At the request of the California Attorney General's Office, I analyzed the discussion of economic analysis of potential greenhouse gas regulation in EPA's Advance Notice of Public Rulemaking (ANPRM) and Technical Supporting Document (TSD).

Summary:

EPA's ANPRM and TSD display an impressive awareness of most of the major issues concerning the economics of climate change, but stop short of following these issues to their logical implications. A commendable review of the big picture, recognizing several recent developments, is followed by a reliance on a small number of traditional methods and models. EPA should be encouraged to think as creatively about models and policy analysis as it did about the nature of climate crisis. Meanwhile, the numerical estimates and partial literature review in these documents should not be used as the basis for policy.

What EPA did right:

The TSD (in particular, section 3, pp. 4-9) raises many important theoretical points, echoed briefly in the ANPRM (sections G.1 – G.3, pp. 44414-44415):

- the need for a very low discount rate for intergenerational analyses
- the centrality of low-probability, catastrophic risks, and the inherent uncertainty in evaluating these threats
- the impossibility of monetizing all benefits, and the resulting indeterminacy in any cost-benefit calculations
- the absurdity of evaluating U.S. climate policy on the basis of U.S. impacts alone, in isolation from the impacts on the rest of the world

Taken together, these points argue for a global analysis, focusing on safe minimum standards and prevention of catastrophe over generations to come, paying little or no attention to the narrowly constrained cost-benefit calculations and marginal cost / marginal benefit estimates that have appeared in a number of past economic analyses. Indeed, EPA's theoretical framework in these documents suggests, in keeping with much of the recent discussion of climate change, that immediate, large-scale policy responses are essential if we hope to ensure a sustainable future with a manageable climate.

Where EPA falls short:

The TSD and ANPRM follow this general discussion with a very partial review of quantitative estimates that have appeared in the economics literature (TSD section 4, pp. 10-18; ANPRM section G.4, pp. 444-15-44416). While claiming to represent the peer-reviewed literature as a whole, this discussion presents only a small subset of that literature, relying primarily on the work of one economist, Richard Tol, who advocates a very low carbon tax.

The discussion of specific estimates offers a contrast between results of an economic model of climate impacts, FUND, and a meta-analysis of the economic literature. However, almost nothing is said about the choice of FUND, the model created by Richard Tol; other models are available, built on differing assumptions and yielding different results. While FUND is touted as being able to generate consistent global and domestic cost estimates, 25 of the 45 domestic U.S. estimates from FUND cited in the TSD are zero, 20 of them with a footnote suggesting that this estimate may be inaccurate (TSD, Table 1, p. 12). This performance hardly inspires confidence in the appropriateness of the model that EPA has chosen. Tol's controversial opinions, incorporated into FUND and his other work, include his belief that the world as a whole will enjoy enormous health *benefits* from the first few decades of global warming, substantially lowering the net costs of climate change. (For documentation and critique of this assumption, see Frank Ackerman and Elizabeth A. Stanton, "A comment on 'Economy-wide estimates of the implications of climate change: Human health," *Ecological Economics* vol. 66 no. 1, May 2008, 8-13.)

Tol is also the author of the meta-analysis of estimates of the social cost of carbon (SCC) cited in the TSD. Tol's latest version of his meta-analysis (Tol 2007, citation and link in the TSD's reference list) surveys 211 estimates from 47 studies. the appendix to that meta-analysis shows that Tol himself is the author or co-author of 96 of the 211 estimates he includes. Even among the other estimates, there is less variety than one might guess: for example, one economist (William Nordhaus) running successive updates of the same model (DICE), either alone or with coauthors, accounts for 7 of the 47 studies, performed in 1982, 1991, 1993, 1996, 1997, and 2000. None of these 7 studies represent Nordhaus' latest work; and they clearly do not represent seven independent analyses (which is how Tol treats them). Although a scattering of dissenting opinions are included in Tol's survey, the database for the meta-analysis is heavily weighted toward the work of a handful of economists such as Tol and Nordhaus. The Stern Review (see below) is included as just one of the 211 estimates; Tol maintains that it is an extreme outlier, and refers to both the Stern Review and the IPCC's latest report as "dodgy analysis."

There are many other voices in the climate economics debate, which receive little or no mention in EPA's documents. Of the economists whose work generally argues for taking the climate threat more seriously, only Martin Weitzman receives a passing mention for his analysis of uncertainty. Weitzman's analysis is more far-reaching than EPA suggests; under plausible assumptions, he demonstrates that the social cost of carbon – that is, the benefit of reducing carbon emissions – could, technically speaking, be infinite. (See the Weitzman articles cited in the TSD.) This possibility defeats any hope of cost-benefit analysis, and suggests placing an absolute priority on reduction of carbon emissions to a safely low level.

The most glaring omission in the TSD and ANPRM is the lack of any mention of the Stern Review. Nicholas Stern, a London School of Economics professor who was formerly chief economist of the World Bank and a prominent member of the UK Treasury Department, was asked in 2005 by then-Chancellor Gordon Brown to review the economics of climate change and climate policy. Stern's massively documented and carefully argued report, released in late 2006, has transformed the academic discussion of the topic. Indeed, one of the Weitzman articles cited in the TSD is Weitzman's response to Stern (and is literally the only mention of Stern in the TSD bibliography).

Stern presented a powerful argument for taking immediate, large-scale action, addressing many of the issues that EPA discusses in its theoretical framework. Stern's Chapter 2 is a remarkable and forceful account of the economic arguments about intergenerational discounting, explaining Stern's conclusion that the rate of pure time preference (the discount rate that would prevail if all generations were equally wealthy) should be very close to zero. His treatment of uncertainty is a great advance over standard analyses, although not quite as ambitious as Weitzman in this respect. He documents numerous studies of costs and benefits, suggesting that even a very partial accounting of the benefits of carbon reduction far outweighs the costs. His work has been effectively adopted as the analytical basis for British climate policy, and is being discussed widely around the world. Economists including Nobel laureates Kenneth Arrow, Joseph Stiglitz, and Amartya Sen have endorsed Stern's conclusions.

The omission of the Stern Review and the subsequent debate is a fatal flaw in any contemporary review of the literature on climate economics. Stern and other members of his team have published extensive responses to their critics, in economics and policy journals. But Stern is not alone in arguing that sound economics endorses massive, prompt intervention to reduce emissions. Economists such as Stephen DeCanio (UC-Santa Barbara); Richard Howarth (Dartmouth); William Cline (Petersen Institute); and Cambridge University economists Terry Barker, Michael Grubb, and Chris Hope have all published extensively in the peer-reviewed literature (as I have as well), along lines broadly consistent with Stern; none of those names appear in the TSD bibliography.

One problem is that peer-reviewed *economics* journals have often taken a narrow view of the field. To an extent that is often surprising to those in law and other disciplines, there is an orthodoxy that reigns over the leading economics journals, and excludes dissenting opinion. Much of the debate has taken place in (peer-reviewed) energy, climate, and public policy journals, such as *Energy Policy*, *Energy Journal*, *Climate Policy*, and *Climatic Change.* Such journals, at their best, provide a fruitful interchange between economists and scientists interested in climate change, which is unlikely to occur in economics journals. The TSD bibliography includes only one such article, a piece in *Energy Policy* by Tol.

Recommendations:

1. A much broader literature review is needed, incorporating the Stern Review and the subsequent debate, and discussing the full range of views on climate economics that can be found in the peer-reviewed literature in economics, energy, climate, and public policy journals.

2. The choice of the FUND model as the sole source for projections should be re-examined; the assumptions built into FUND should be vetted and compared to those in alternative models. (I have co-authored a literature review on such models, which has been submitted to the journal *Climate and Development* for publication. A draft of the article is attached to these comments.)

3. EPA solicits comment on three topics in the ANPRM:

a) "…the considerations raised and discounting alternatives for handling both benefits and costs for this long-term, inter-generational context" (section G.2, p. 44415)

b) "…how to handle uncertainty in benefits and costs calculations and application, given the quantified and unquantified uncertainties" (section G.3, p. 44415)

c) "…the appropriateness of using U.S. and global values in quantifying the benefits of GHG reductions and the appropriate application of benefits estimates given the state of the art and overall uncertainties" (section G.4, p. 44416)

The most important comment in response to these questions is that c) is not an independent question; the answer to it is determined (or made irrelevant) by a) and b). In the very long time frame of climate analyses, as a) suggests, costs and benefits cannot be meaningfully compared without some decision about discounting; that decision determines the present value of costs and benefits, and is decisive in any evaluation of policy options. Stern's treatment of discounting offers a compelling response to this point, in much more detail.

In the presence of fundamental uncertainties, as b) suggests, with potentially catastrophic outcomes becoming ever more likely as the planet warms, worst-case risks dominate any ordinary calculation of costs and benefits. As Stern, Weitzman, and others have argued, an appropriate policy response should be based on what is needed to immediately reduce worst-case risks to an acceptable level, not on fine-tuning guesses about the most likely outcomes. Given those two fundamental points, the quantified estimates collected by EPA, largely resulting from the work of one controversial economist, add very little to the discussion.

4. The need for vetting the assumptions in a complex model is also the most important response to the discussion of transportation modeling (ANPRM, pp. 44443 – 44447). This discussion has an "inside baseball" quality, and will be meaningful primarily to those who are intimately familiar with DOT's "Volpe Model." Transparency requires a description of the key model assumptions and an affirmative argument for the merits of this model, beyond its availability and complexity – the two points made most clearly on its behalf in the ANPRM. Is the universe of possible improvements in fuel efficiency adequately spanned by a uniform 4% per year improvement and the results of the Volpe Model? Is the experience of other countries and the availability of new technologies also worth discussing? Should the promotion of car-sharing (e.g. "Zipcar"), bicycling, and transit options be considered, along with fine-tuning the modeling of fuel efficiency changes? If the goal is cost-effective reduction in transportation emissions, these broader alternatives may contribute at least as much as a more complex analysis of consumer choice in the new car market.

Attachment to Comments of Dr. Frank Ackerman

Inside the Integrated Assessment Models:
Four Issues in Climate Economics

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Inside the Integrated Assessment Models: Four Issues in Climate Economics

Abstract: Good climate policy requires the best possible understanding of how climatic change will impact on human lives and livelihoods in both industrialized and developing counties. Our review of recent contributions to the climate-economics literature assesses 30 existing integrated assessment models in terms of four key aspects of the nexus of climate and the economy: the connection between the model structure and the type of results produced; uncertainty in climate outcomes and the projection of future damages; equity across time and space; and abatement costs and the endogeneity of technological change. Differences in treatment of these issues are substantial, and directly affect model results and their implied policy prescriptions. Much can be learned about climate economics and modeling technique from the best practices in these areas; there is unfortunately no existing model that incorporates the best practices on all or most of the questions we examine.

I. Introduction

There is no shortage of models that join climate to economy with the goal of predicting the impacts of greenhouse gas emissions in the decades to come and offering policy advice on when, where, and by how much to abate emissions. Some models are designed to offer a detailed portrayal of the climate, or the process of economic growth, or the feedback between these two systems; others focus on the long-run or the short-run, economic damages or environmental damages, carbon-based energy sectors or abatement technology. The best models produce results that inform and lend clarity to the climate policy debate. Some models surprisingly conclude – in direct contradiction of the urgency expressed in the scientific literature – that rapid, comprehensive emissions abatement is both economically unsound and unnecessary. And some models seem to ignore (and implicitly endorse the continuation of) gross regional imbalances of both emissions and income.

Good climate policy requires the best possible understanding of how climatic change will impact on human lives and livelihoods, in industrialized countries and in developing countries. No model gets it all right, but the current body of climate-economics models and theories contains most of the ingredients for a credible model of climate and development in an unequal world.

Unfortunately, many climate-economics models suffer from a lack of transparency, in terms of both their policy relevance and their credibility. Building a model of the climate and the economy inevitably involves numerous judgment calls; debatable judgments and untestable hypotheses turn out to be of great importance in determining the policy recommendations of climate-economics models, and should be visible for debate.

A good climate-economics model would be transparent enough for policy relevance, but still sophisticated enough to get the most important characteristics of the climate and the economy right. Unfortunately, many existing models fall short of one or both criterion: some are very complex – often entirely opaque to the non-specialist – and some represent the climate and economy incorrectly, as discussed below.

Our review of recent contributions to the climate-economics literature assesses 30 existing integrated assessment models (IAMs) in terms of four key aspects of the nexus of climate and the economy:

- choice of model structure and the type of results produced
- uncertainty in climate outcomes and the projection of future damages
- equity across time and space
- abatement costs and the endogeneity of technological change.

The next four sections of this review evaluate the body of existing climate economics models in terms of these key model characteristics, with illustrative examples of both problems and solutions taken from the literature. The concluding section summarizes our findings and their implications for the construction of climate-economics models.

II. Choice of model structure

This review examines 30 climate-economics models, all of which have been utilized to make contributions to the IAM literature within the last ten years.[1] These models fall into five broad categories, with some overlap: welfare optimization, general equilibrium, partial equilibrium, simulation, and cost minimization (see Table 1).[2] Each of these structures has its own strengths and weaknesses, and each provides a different perspective on the decisions which are necessary for setting climate and development policy. In essence, each model structure asks a different question and that question sets the context for the results it produces.

[1] Two climate-economics modeling projects published as special issues of the Energy Journal were indispensible in preparing this review. The first was organized by the Stanford Energy Modeling Forum (Weyant and Hill 1999) and the second by the Innovation Modeling Comparison Project (Edenhofer, Lessmann, Kemfert *et al.* 2006; Grubb *et al.* 2006; Köhler *et al.* 2006).

[2] A sixth category, macroeconomic models, could be added to this list, although the only example of a pure macroeconomic model being used for climate analysis may be the Oxford Global Macroeconomic and Energy Model (Cooper *et al.* 1999). Publically available documentation for this model is scarce and somewhat cryptic, perhaps because it was developed by a private consulting firm. Macroeconomic models include unemployment, financial markets, international capital flows, and monetary policy (or at least some subset of these) (Weyant and Hill 1999). Three general equilibrium or cost minimization models with macroeconomic features are included in this literature review, G-CUBED/MSG3, MIND, and MESSAGE-MACRO.

Table 1: Climate-economics models reviewed in this study

Model Category	Global	Regionally Disaggregated
Welfare Maximization	DICE-2008 ENTICE-BR DEMETER-1CCS *MIND*	RICE-2004 FEEM-RICE FUND MERGE CETA-M GRAPE AIM/Dynamic Global
General equilibrium	JAM IGEM	IGSM/EPPA SMG WORLDSCAN ABARE-GTEM G-CUBED/MSG3 MS-MRT AIM IMACLIM-R WIAGEM
Partial Equilibrium		MiniCAM *GIM*
Simulation		PAGE-2002 ICAM-3 E3MG *GIM*
Cost Minimization	GET-LFL *MIND*	DNE21+ MESSAGE-MACRO

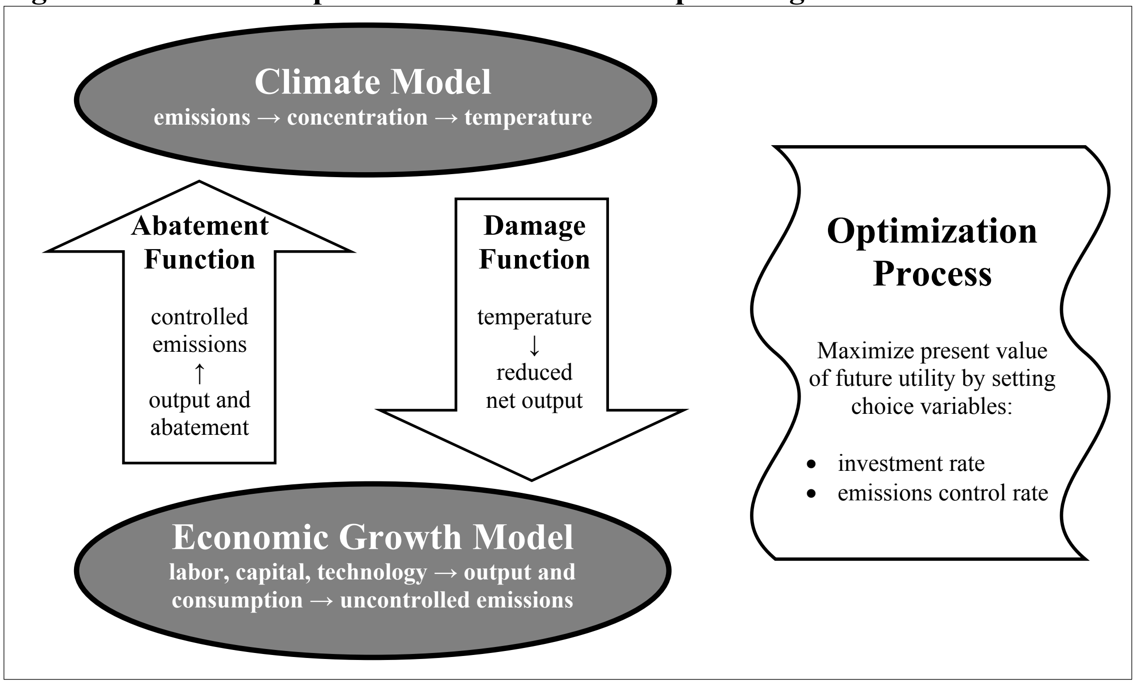
Note: Italics indicate that a model falls under more than one category.

Differences in model structures

Welfare optimization models tend to be fairly simple, which adds to their transparency. Production causes both emissions and consumption. Emissions affect the climate, causing damages that reduce production. The models maximize the discounted present value of welfare (which grows with consumption, although at an ever-diminishing rate)[3] across all time periods by choosing how much emissions to abate in each time period, where abatement costs reduce production (see Figure 1). The process of discounting welfare (or "utility," which is treated as a synonym for welfare here and in many models) requires imputing speculative values to non-market "goods" like ecosystems or human lives, as well as assigning a current value to future costs and benefits. Dynamic optimization models – including all of the welfare optimization and cost minimization models reviewed here – solve all time periods simultaneously, as if decisions could be made with perfect foresight.

[3] In these models, consumption's returns to welfare are always positive but diminish as we grow wealthier. Formally, the first derivative of welfare is always positive and the second is always negative. A popular, though not universal, choice defines individual welfare, arbitrarily, as the logarithm of per capita consumption or income.

Figure 1: Schematic representation of a welfare optimizing IAM



Our review of climate-economics models includes four global welfare optimization models – DICE-2007 (Nordhaus 2008), ENTICE-BR (Popp 2006), DEMETER-1CCS (Gerlagh 2006), and MIND (Edenhofer, Lessmann and Bauer 2006) – and seven regionally disaggregated welfare maximization models – RICE-2004 (Yang and Nordhaus 2006), FEEM-RICE (Bosetti *et al.* 2006), FUND (Tol 1999), MERGE (Manne and Richels 2004), CETA-M (Peck and Teisberg 1999), GRAPE (Kurosawa 2004), and AIM/Dynamic Global (Masui *et al.* 2006).

General equilibrium models represent the economy as a set of linked economic sectors (labor, capital, energy, etc.). These models are solved by finding a set of prices that have the effect of "clearing" all sectors simultaneously (that is, a set of prices that simultaneously satisfy demand and supply in every sector). General equilibrium models tend to use "recursive dynamics" – setting prices in each time period and then using this solution as the beginning point for the next period (thus assuming no foresight at all). Eleven general equilibrium models are reviewed in this study: JAM (Gerlagh 2008), IGEM (Jorgenson *et al.* 2004), IGSM/EPPA (Babiker *et al.* 2008), SMG (Edmonds *et al.* 2004), WORLDSCAN (Lejour *et al.* 2004), ABARE-GTEM (Pant 2007), G-CUBED/MSG3 (McKibbin and Wilcoxen 1999), MS-MRT (Bernstein *et al.* 1999), AIM (Kainuma *et al.* 1999), IMACLIM-R (Crassous *et al.* 2006), and WIAGEM (Kemfert 2001).

In dynamic versions of general equilibrium theory, multiple equilibria cannot always be ruled out (Ackerman 2002). When multiple equilibria are present, general equilibrium models yield indeterminate results which may depend on details of the estimation procedure. For this reason, an assumption of constant or decreasing returns is often added to their production functions, an arbitrary theoretical restriction which is known to assure a single optimal result (Köhler *et al.* 2006). Because increasing returns to scale are important to accurate modeling of endogenous technological change, general equilibrium modelers must skirt between oversimplifying their representation of the energy sector and allowing unstable model results. *Partial equilibrium models* – e.g. MiniCAM (Clarke *et al.* 2007) and GIM (Mendelsohn and Williams 2004) – make use of a subset of the general equilibrium apparatus, focusing on a smaller number of economic sectors by holding prices in other sectors constant; this procedure also can help to avoid problems with increasing returns to scale.

Simulation models are based on off-line predictions about future emissions and climate conditions; climate outcomes are not affected by the economic model. Rather, a predetermined set of emissions values by period dictates the amount of carbon that can be used in production, and model output includes the cost of abatement and cost of damages. Simulation models cannot, in and of themselves, answer questions of what policy makers *should* do to maximize social welfare or minimize social costs. Instead, the simulation models reviewed in this study – PAGE2002 (Hope 2006), ICAM-3 (Dowlatabadi 1998), E3MG (Barker *et al.* 2006), and GIM (Mendelsohn and Williams 2004) – estimate the costs of various likely future emission paths.

Cost minimization models are designed to identify the most cost effective solution to a climate-economics model. Some cost minimization models explicitly include a climate module, while others abstract from climate by representing only emissions, and not climatic change and damages. The four cost minimization models included in this review – GET-LFL (Hedenus *et al.* 2006), MIND (Edenhofer, Lessmann and Bauer 2006), DNE21+ (Sano *et al.* 2006), and MESSAGE-MACRO (Rao *et al.* 2006) – have very complex "bottom up" energy supply sectors, modeling technological choices based on detailed data about specific industries. Three of these models, excluding GET-LFL, combine a bottom-up energy supply sector with a top-down energy end-use sector, modeling technology from the vantage point of the macroeconomy.

Evaluation of model structures

The different types of model structures provide results that inform climate and development policy in very different ways. All five categories have strengths and weaknesses. Many of the best-known IAMs attempt to find the "optimal" climate policy, one that maximizes long-term human welfare. This calculation depends on several unknowable or controversial quantities, including the numerical measurement of human welfare, the physical magnitude and monetary value of all current and anticipated climate damages, and the relative worth of future versus present benefits.

General equilibrium models can be extremely complex, combining very detailed climate models with intricate models of the economy; yet despite their detail, general equilibrium models' reliance on decreasing returns is a serious limitation to their usefulness in modeling endogenous technological change. Partial equilibrium models circumvent the problem of increasing returns, at the cost of a loss of generality. In some cases, there appears to be a problem of spurious precision in overly elaborated models of the economy, with, for example, projections of long-term growth paths for dozens of economic subsectors.

Simulation models are well suited for representing uncertain parameters and for developing IAM results based on well-known scenarios of future emissions, but their policy usefulness is limited by a lack of feedback between their climate and economic dynamics. Finally, cost minimization models address policy issues without requiring calculations of human welfare in money terms, but existing cost minimization models may suffer from the same tendency towards spurious precision exhibited in some general and partial equilibrium models.

III. Uncertain outcomes and projections of future damages

IAMs inevitably rely on forecasts of future climate outcomes and the resulting economic damages, under conditions that are outside the range of human experience. This aspect of the modeling effort raises two related issues: the treatment of scientific uncertainty about climate change, and the functional relationships used to project future damages.

Scientific uncertainty in climate outcomes

There are inescapable scientific uncertainties surrounding climate science, for instance in the climate sensitivity parameter (the temperature increase resulting from a doubling of CO_2 concentrations). As a result, low-probability, enormous-cost climate outcomes cannot be ruled out; the response to these extreme risks is often central to policy debate, and would ideally be incorporated in economic models of climate change. Yet we found that most IAMs use central or average estimates to set parameter values. Those few models that express parameter values as distributions most often use truncated distributions that inappropriately exclude or de-emphasize low-probability, high-cost catastrophes.

Uncertainty is inescapable, despite the ever-expanding body of climate research, because there are only a limited number of empirical observations relevant to questions such as estimation of the climate sensitivity parameter. As a result, the best estimates of the relevant probability distributions inevitably exhibit “fat tails,” meaning that extreme outcomes are much more likely than a normal distribution would imply (Weitzman 2008). According to Martin Weitzman, an economist who has raised this problem in recent debate, IPCC (2007) data implies that an atmospheric concentration of 550 ppm of CO_2-equivalent would lead to a 98^{th} percentile chance of 6ºC increase in temperature, a point at which we “are located in the terra incognita of … a planet Earth reconfigured as science fiction… [where] mass species extinctions, radical alterations of natural environments, and other extreme outdoor consequences will have been triggered by a geologically-instantaneous temperature change that is significantly larger than what separates us now from past ice ages.” (Weitzman 2007, p.716).[4]

In the face of such worst-case risks, it is misleading to look only at the most likely range of conditions. That approach would take for granted policy-makers’ willingness to play the odds in crafting a response to rising global emissions: Suppose that we knew that there were one hundred equally likely future scenarios, of which only one or a few would experience truly catastrophic climate change. The future will happen only once. If we plan well for the most likely outcomes but instead one that we consider unlikely comes to pass, will we be comforted by our parsimonious rationality?

The most common approach to uncertainty found in the IAM literature is off-line sensitivity analysis, often conducted by changing one parameter value at a time and observing the results. A more thorough treatment of uncertainty, through Monte Carlo analysis that varies multiple unknown parameters, is seen in just a few IAMs, and even then it is difficult to fully explore the parameter space, especially given the fat-tailed distributions that characterize many key climate parameters, and their poorly understood correlations.

One of the best-known models that incorporates Monte Carlo analysis of uncertain parameter values is the model used in the Stern Review (Stern et al. 2006) – Chris Hope’s PAGE2002 model (Hope 2006). PAGE2002 includes triangular distributions for 31 uncertain parameters; Hope’s standard analysis is based on 1000 iterations of the model; as in other multivariate Monte Carlo analyses, he uses Latin Hypercube sampling[5] to select the uncertain parameters. Even this modest level of sensitivity analyses has a major impact on results. For the Stern Review, introducing the Monte Carlo analysis instead of simply using the modal parameter values increases the expected value of annual climate damages by an average of 7.6 percent of world output (Dietz *et al.* 2007).

The 31 uncertain parameters in PAGE2002 include two sets of seven regional parameters, but there are still 19 orthogonal (that is, presumed unrelated or independent) parameters with independent distributions to be sampled for each iteration. This makes it essentially impossible for a Monte Carlo analysis to explore simultaneous worst cases in all or most of the parameters. To have, on average, at least one iteration with values from the worst quintile for all 19 parameters, it would be necessary to run the model an unimaginable 20 trillion times – a result of the so-called “curse of dimensionality” (Peck and Teisberg 1995). Of course, many parameters that are orthogonal in the model may be interdependent in the real world; for example, the warming that results from a doubling of carbon dioxide in the atmosphere and the release of natural carbon dioxide, or the scale of economic and non-economic benefits. A greater interdependency among parameters

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[4] In more recent work, Weitzman has suggested that climate science implies even greater risks at the 95th-99th percentile (Weitzman 2008). Of course, his argument does not depend on an exact estimate of these risks; the point is that accuracy is unattainable and the risks do not have an obvious upper bound, yet effective policy responses must be informed by those low-probability extreme events.

[5] Latin Hypercube sampling, a technical procedure widely used in Monte Carlo analyses, ensures that the selected sets of parameters are equally likely to come from all regions of the relevant parameter space.

would make seemingly rare extreme events (based on multiple worst-case parameter values) more likely. But as long as these parameters are represented as orthogonal in probabilistic IAMs, a very high number of iterations will be necessary to assure even a single run with extreme values for all parameters. In PAGE2002, with just 1000 iterations, it is highly unlikely that there are any results for which more than a few parameters are assigned 95th percentile or worse values.

Only one other model among those reviewed has a built-in method of randomizing parameter values. Carnegie Mellon's ICAM is a stochastic simulation model that samples parameter values from probability distributions for 2000 parameters for an unspecified number of iterations (Dowlatabadi 1998). An enormous number of iterations would be necessary to assure even one result with low-probability values for any large subset of these parameters. With any plausible number of iterations, the "curse of dimensionality" means that the primary choice being made by the Monte Carlo sampling is the selection of which parameters happen to have their worst cases influence the results of the analysis. Suppose that worst-quintile values for a particular set of 5 parameters in PAGE2002, or 50 in ICAM, interact in a nonlinear manner to produce a catastrophe; it is extremely likely that a Monte Carlo analysis of merely a few thousand iterations would completely miss this interaction.[6]

Several studies have added a Monte Carlo analysis onto some of the other IAMs reviewed here.[7] Nordhaus and Popp (Nordhaus and Popp 1997) ran a Monte Carlo analysis on a modification of an earlier version of the DICE model – called PRICE – using eight uncertain parameters and 625 iterations, with five possible values for each of three parameters and a variation on Latin Hypercube sampling for the rest; again, so few iterations can reveal little about the tails of the distribution. Nordhaus also runs a Monte Carlo simulation of his more recent version of DICE-2007 (Nordhaus 2008) with eight parameters and 100 iterations, saying

> We assume normal distributions primarily because we fully understand their properties. We recognize that there are substantial reasons to prefer other distributions for some variables, particularly ones that are skewed or have "fat tails," but introducing other distributions is highly speculative at this stage and is a more ambitious topic than the limited analyses that are undertaken here… (p.127-128)

Monte Carlo experiments exist in the literature for several other deterministic models. Kypreos (Kypreos 2008) adds five stochastic parameters to MERGE and runs 2500 iterations; Peck and Teisberg (Peck and Teisberg 1995) add one stochastic parameter to CETA-R with an unreported number of iterations; and Scott and co-authors (Scott *et al.*

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[6] If the uncertain parameters were all truly independent of each other, such combinations of multiple worst-case values would be extraordinarily unlikely. The danger is that the uncertain parameters, about which our knowledge is limited, may not be independent. If plausible events or research findings would lead to multiple worst-case values, then there is a risk which Monte Carlo analysis will usually miss due to the "curse of dimensionality." The greater the number of Monte Carlo parameters, the greater this risk becomes.

[7] For an earlier review of attempts to incorporate uncertainty in IAMs see (Scott *et al.* 1999).

1999) add 15 stochastic parameters to MiniCAM with an unreported number of iterations. Webster, Tatang and McRae (Webster *et al.* 1996) take a different approach to modeling uncertainty in ISGM/EPPA by using a collocation method that approximates the model's response as a polynomial function of the uncertain parameters.

None of the models reviewed here assume fat-tailed distributions and reliably sample the low-probability tails. Therefore, none of the models provide adequate information for formulating a policy response to the worst-case extreme outcomes that are unfortunately not unlikely enough to ignore.

Projecting future damages

Most IAMs have two avenues of communication between their climate model and their economic model: a damage function and an abatement function (see Figure 1 above). The damage function translates the climate model's output of temperature – and sometimes other climate characteristics, like sea-level rise – into changes to the economy, positive or negative.

Many models assume a simple form for this relationship between temperature and economic damage, such that damages rise in proportion to a power of temperature change:

1) $D = aT^b$

where D is the value of damages (in dollars or as a percent of output), T is the difference in temperature from that of an earlier period, and the exponent b determines the shape or steepness of the curve. Implicitly, the steepness of the damage function at higher temperatures reflects the probability of catastrophe – a characteristic that can have a far more profound impact on model results than small income losses at low temperatures.

Our literature review revealed three concerns with damage functions in existing IAMs: The choice of exponents and other parameters for many damage functions are either arbitrary or under-explained; the form of the damage function constrains models' ability to portray discontinuities; and damages are commonly represented in terms of losses to income, not capital.

Arbitrary exponent

DICE, like a number of other models, assumes that the exponent in the damage function is 2 – that is, damages are a quadratic function of temperature change.[8] The DICE-2007 damage function was assumed to be a quadratic function of temperature change with no damages at 0ºC temperature increase, and damages equal to 1.8 percent of gross world

[8] DICE-2007 actually uses a slightly more complicated equation which is equivalent to our equation 1), with the exponent b=2, for small damages.

output at 2.5ºC; this implies, for example, that only 10.2 percent of world output is lost to climate damages at 6ºC. (Nordhaus 2007a).[9] Numerous subjective judgments, based on fragmentary evidence at best, are incorporated in the point estimate of 1.8 percent damages at 2.5ºC (much of the calculation is unchanged from (Nordhaus and Boyer 2000), which provides a detailed description). The assumption of a quadratic dependence of damage on temperature rise is even less grounded in any empirical evidence.

Many models assert key parameters, like those of the damage function, with little or no explanation or justification. The GRAPE model (Kurosawa *et al.* 1999, p.163), for example, asserts its damage function parameters without any justification, but concedes that "It is an open question how climate change impacts should be assessed qualitatively and quantitatively." The MERGE model attributes its damage parameters to "the literature" (Manne and Richels 2004); Manne and Richels comment that, "Admittedly, the parameters of this loss function are highly speculative. With different numerical values, different abatement policies will be optimal. This helps to explain why there is no current international consensus on climate policy." (p.2-3)

Our review of the literature uncovered no rationale, whether empirical or theoretical, for adopting a quadratic form for the damage function – although the practice is endemic in IAMs, especially in those that optimize welfare. PAGE2002 (Hope 2006) uses a damage function calibrated to match DICE, but makes the exponent an uncertain (Monte Carlo) parameter, with minimum, most likely, and maximum values of 1.0, 1.3, and 3.0, respectively. Sensitivity analyses of the Stern Review (Stern et al. 2006) results, which were based on PAGE2002, show that fixing the exponent at 3 – assuming damages are a cubic function of temperature – increases annual damages by a remarkable 23 percent of world output (Dietz *et al.* 2007). Thus the equally arbitrary assumption that damages are actually a cubic function of temperature rather than quadratic would have a very large effect on IAM results, and consequently on their policy implications.

<u>Continuity</u>

Damage functions are often defined to be continuous across the entire range of temperature rise, even though it is far from certain that climate change will in fact be gradual and continuous. Several climate feedback processes point to the possibility of an abrupt discontinuity at some uncertain temperature threshold or thresholds. However, only a few IAMs instead model damages as discontinuous, with temperature thresholds at which damages jump to much worse, catastrophic outcomes.

Two leading models incorporate some treatment of catastrophic change, while maintaining their continuous, deterministic damage functions. MERGE (Manne and Richels 2004) assumes all incomes fall to zero when the change in temperature reaches 17.7 ºC – which is the implication of the quadratic damage function in MERGE, fit to its assumption that rich countries would be willing to give up 2 percent of output to avoid 2.5 ºC of temperature rise. This formulation deduces an implicit level of catastrophic

[9] See (Ackerman *et al.* 2008) for a more detailed critique of the DICE-2007 damage function.

temperature increase, but maintains the damage function's continuity. DICE-2007 (Nordhaus 2007b) models catastrophe in the form of a specified (moderately large) loss of income, which is multiplied by a probability of occurrence (an increasing function of temperature), to produce an expected value of catastrophic losses. This expected value is combined with estimates of non-catastrophic losses, to create the DICE damage function; that is, it is included in the quadratic damage function discussed above.

In the PAGE2002 model (Hope 2006), the probability of a catastrophe increases as temperature rises above some specified temperature threshold. The threshold at which catastrophe first becomes possible, the rate at which the probability increases as temperature rises above the threshold, and the magnitude of the catastrophe when it occurs, are all Monte Carlo parameters with ranges of possible values.

Income damages

Damages are commonly modeled in IAMs as losses to income or consumption, leaving capital stocks and productivity undiminished for future use. For example, non-catastrophic damages in the DICE-2007 model (Nordhaus 2007a) include impacts to agriculture, "other vulnerable markets", coastal property from sea-level rise, health, time-use, and "human settlements and natural ecosystems", all of which are subtracted directly from total economic output. Many of these categories seem more like reductions to capital than income, especially coastal property and human settlements damages. Others seem like they would have multi-period effects on the marginal productivity of capital or labor, that is, the ability of technology to transform capital and labor into income; damages to agricultural resources and health are good examples of longer-term changes to productivity.

When damages are subtracted from output, the implication is that these are one time costs that are taken from consumption, with no effects on capital, production, or consumption in the next period – an unrealistic assumption even for the richest countries, as attested by the ongoing struggle to rebuild New Orleans infrastructure, still incomplete three years after Hurricane Katrina. FUND (Tol 1999) is unusual among welfare optimizing IAMs in that it models damages as one-time reductions to both consumption and investment, where damages have lingering "memory" effects determined by the rate of change of temperature increase.

It would be possible to develop an IAM that modeled climate damages as, at least in part, losses of capital stock and/or decreases in productivity. This would require a model design only slightly more complicated than the common structure sketched in Figure 1: climate damages would alter the inputs to the production function that determines output, or the parameters of that function which express productivity, rather than just reducing the amount of available output after it is constructed. It would build in "memory," with multi-period consequences of major climate impacts, a realistic feature that could be implemented relatively transparently.

IV. Equity across time and space

Most climate economic models implicitly assume that little attention is needed to the problems of equity across time and space. In the area of intertemporal choice, most models have high discount rates that inflate the importance of the short-term costs of abatement relative to the long-term benefits of averted climate damage. Together with the common assumption that the world will grow richer over time, discounting gives greater weight to earlier, poorer generations relative to later, wealthier generations.

Equity between regions of the world, in the present or at any moment in time, is intentionally excluded from most IAMs, even those that explicitly treat the regional distribution of impacts. In such regionally disaggregated models, any simple, unconstrained attempt to maximize human welfare would generate solutions that include large transfers from rich to poor regions. To prevent this "problem" from dominating their results, IAMs employ "Negishi welfare weights" (based on theoretical analysis in (Negishi 1972)), which constrain possible solutions to those which are consistent with the existing distribution of income. In effect, the Negishi procedure imposes an assumption that human welfare is more valuable in richer parts of the world.

Equity across time

The impacts of climate change, and of greenhouse gas mitigation, will stretch centuries or even millennia into our future. Models that estimate welfare, income, or costs over many years must somehow value gains and losses from different time periods. The early work of Frank Ramsey (Ramsey 1928) provides the basis for the widely used "prescriptive" approach, in which there are two components of the discount rate: the rate of pure time preference, or how human society feels about costs and benefits to future generations, regardless of the resources and opportunities that may exist in the future; and a wealth-based component – an elasticity applied to the rate of growth of real consumption – that reflects the diminishing marginal utility of income over time as society becomes richer.

Algebraically, the discount rate, $r(t)$, combines these two elements: it is the rate of pure time preference, ρ, plus the product of the elasticity of marginal utility with respect to consumption
per capita, η, and the growth rate of income or consumption per capita, $g(t)$.

2) $$r(t) = \rho + \eta g(t)$$

Because climate change is a long-term problem involving long time lags, climate-economics models are extremely sensitive to relatively small changes in the assumed discount rate. There are long-standing debates on the subject, which are summarized well in the Stern Review (Stern et al. 2006). Remarkably, given the prominence of the discount rate debates, the model descriptions for many IAMs do not state the discount rate they use, or any of its components. Indeed, a number of papers refer to discounting but offer no information about the rates and methodologies they use. Some use the alternative, "descriptive" approach to discounting, where the market rate of interest or capital growth is taken to represent the discount rate.[10] These analyses typically either set the discount rate at 5 percent, or at an unspecified market rate of interest (for example, Charles River Associates' MS-MRT (Bernstein *et al.* 1999), a general equilibrium model).

Choices about the discount rate inevitably reflect value judgments made by modelers. The selection of a value for the pure rate of time preference is a problem of ethics, not economic theory or scientific fact. Pure time preference of 0 would imply that (holding real incomes constant) benefits and costs to future generations are just as important as the gains and losses that we experience today. The higher the rate of pure time preference, the less we value harm to future generations from climate change and the less we value the benefits that we can confer on future generations by averting climate change. Pure rates of time preference found in this literature review range from 0.1 percent in the Stern Review's PAGE2002 analysis (Hope 2006) to 3 percent in RICE-2004 (Yang and Nordhaus 2006).

Only a few model descriptions directly state their elasticity of marginal utility of consumption and growth rate, although the use of this elasticity, implying that marginal utility declines as consumption grows, is common to many IAMs. In DICE-2007 (Nordhaus 2008), the pure rate of time preference is 1.5 percent, elasticity of the marginal utility of consumption is set at 2, and per capita consumption begins growing at 1.6 percent per year but slows to 1 percent over the course of 400 years. The total discount rate for DICE-2007, therefore, declines from 4.7 percent in 2005 down to 3.5 percent in 2395. In the Stern Review's version of PAGE2002 (Hope 2006), the pure rate of time preference is 0.1 percent, the elasticity of the marginal utility of consumption is set at 1, and the growth in per capita consumption averages 1.3 percent, for a total discount rate of 1.4 percent.

A higher elasticity of marginal utility of income reflects a greater emphasis on equity: as long as the elasticity is greater than zero, an increase in income or consumption to a poorer person is worth more to our social welfare than the same absolute increase in income to a richer person.[11] PAGE2002's elasticity of 1 implies a logarithmic utility function. When utility is assumed to be equal to the logarithm of per capita income, a percentage change in income has the same effect on utility regardless of the level of income. For example, a $100 increase to the income of someone with an income of $1000 would have the same impact on utility as a $1 million increase to the income of someone with $10 million.

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[10] The terminology of descriptive and prescriptive approaches was introduced and explained in (Arrow *et al.* 1996).

[11] If the elasticity of the marginal utility of consumption is a constant η, as in equation 2), and per capita consumption is c, then utility = $c^{(1-\eta)}/(1-\eta)$, except when $\eta=1$, when utility = ln c. See the Stern Review technical annex to Chapter 2 on discounting or other standard works on the subject for explanation (Stern et al. 2006).

DICE-2007's elasticity of 2 indicates that utility is proportional to 1 minus the inverse of per capita consumption – a function that is more concave than the natural log – which therefore places a greater emphasis on improvements to income for those at low income levels. Because DICE is a global model – lacking regional disaggregation – there is only one utility function for the world as a whole; the practical upshot of this is that the diminishing marginal utility of income is applicable only in comparisons across time (e.g. the present generation versus the future) and not in comparisons across different regions or socio-economic characteristics (e.g. Africa versus North America today, or at any given point in time).

The four cost minimization models included in this literature review – GET-LFL (Hedenus *et al.* 2006), MIND (Edenhofer, Lessmann and Bauer 2006), DNE21+ (Sano *et al.* 2006), and MESSAGE-MACRO (Rao *et al.* 2006) – all report a 5 percent discount rate.[12] The ethical issues involved in discounting abatement costs are somewhat more straightforward than those involved in discounting welfare. Abatement technologies have well-defined monetary prices, and thus are more firmly situated within the theoretical framework for which discounting was developed. Many abatement costs would occur in the next few decades – over spans of time which could fit within the lifetime and personal decisions of a single individual. To pay for $1000 worth of abatement fifty years from now, for example, one can invest $230 today in a low-risk bond with 3 percent annual interest. On the other hand, welfare optimization models must inevitably assign subjective, contestable values to the losses and gains to future generations that are difficult to monetize, such as the loss of human life or the destruction of ecosystems. No investment today can adequately compensate for a loss of life or irreversible environmental damage; and even if an agreeable valuation were established, there is no existing, or easily imagined, mechanism for compensating victims of climate change several hundred years in the future.

Equity across space

IAMs that optimize welfare for the world as a whole – modeled as one aggregate region – maximize the result of a single utility function by making abatement and investment choices that determine the emissions of greenhouse gases; emissions then determine climate outcomes and damages, one of the inputs into utility. This utility function is a diminishing function of per capita income or per capita consumption. The IAM chooses emission levels for all time periods simultaneously – when more emissions are allowed, future periods lose income to climate damages; when emissions are lowered, abatement costs decrease current income.

The model's optimizing protocol (or more picturesquely, the putative social planner) balances damages against abatement costs with the goal of maximizing utility – not income or consumption. Because utility is modeled with diminishing returns to income, the additions and subtractions to income caused by climate change are only one input into

[12] The MIND model (Edenhofer, Lessmann and Bauer 2006), which combines cost minimization with welfare maximization, uses a pure rate of time preference of 1 percent and a total discount rate of 5 percent.

the optimizing decision. The optimal result also depends on the per capita income level of the time period in which the change to income occurs. A change to income in a rich time period is given a lower weight than an identical change to income in a poor time period (even if the rate of pure time preference is zero). If, as usual, per capita income and consumption are projected to keep growing, the future will be richer than the present. Under that assumption, a more rapidly diminishing marginal utility of income means that the richer future matters less, in comparison to the relatively poorer present.

Regional welfare optimizing IAMs apply the same logic, but with separate utility functions for each region. The model is solved by choosing abatement levels that maximize the sum of utility in all regions. Seemingly innocuous, the disaggregation of global IAMs into component regions raises a gnarly problem for modelers: with identical, diminishing marginal returns to income in every region, the model can increase utility by moving income towards the poorest regions – whether in allocating regionally specific damage and abatement costs, or inducing transfers between regions for the purpose of fostering technical change, or funding adaptation, or purchasing emission allowances, or any other channel available in the model for inter-regional transfers.

Modelers have typically taken this tendency toward equalization of income as evidence of the need for a technical fix. In order to model climate economics without any distracting rush toward global equality, many models apply the little-known technique of "Negishi weights." (Negishi 1972) Stripped of its complexity, the Negishi procedure assigns larger weight to the welfare of richer regions, thereby eliminating the global welfare gain from income redistribution. For examples of how this procedure is discussed in the climate-economics literature see (Kypreos 2005, p.2723; Peck and Teisberg 1997, p.4; Yang and Nordhaus 2006, p.738, 731).

In more detail, the technical fix involves establishing a set of weights for the regional utility functions. The model is run first with no trade or financial transfers between regions; the regional pattern of per capita income and marginal product of capital from that autarkic (no-trade) run is then used to set the so-called Negishi weights, for each time period, that equalize the marginal product of capital across all regions. Since the marginal product of capital is higher in lower-income regions, the Negishi weights give greater importance to utility in higher-income areas. In a second iteration, the normal climate-economics model, with transfers possible between regions, is restored, and the Negishi weights are hard-wired into the model's utility function. The result, according to the model descriptions, is that the models act as if the marginal product of capital were equal in all regions and, therefore, no transfers are necessary to assuage the redistributive imperative of diminishing marginal returns. (For an example of the Negishi weights methodology see (Yang and Nordhaus 2006) or (Manne and Richels 2004).) The (usually) unspoken implication is that the models are acting as if human welfare is more valuable in the richer parts of the world.

Describing the addition of Negishi weights to regional welfare optimization models as a mere technical fix obscures a fundamental assumption about equity. Negishi weights cause the models to maximize welfare as if every region already had the same income per capita – suppressing the obvious reality of vastly different regional levels of welfare, which the models would otherwise highlight and seek to alleviate (Keller *et al.* 2003; Manne 1999; Nordhaus and Yang 1996).

In IAMs that do not optimize welfare, assumptions regarding the interregional effects of a diminishing marginal utility of income are not negated by Negishi weights. For example, in the PAGE2002 (Hope 2006) model – a simulation model that reports regional estimates – no radical equalization of per capita income across regions occurs because utility is not maximized.[13] In a recent assessment of the Stern Review (Stern et al. 2006), Partha Dasgupta (Dasgupta 2007) argues on equity grounds that the PAGE2002 model has an insufficient elasticity of the marginal utility of consumption (recall that PAGE uses $\eta=1$) – or too little emphasis on interregional equity; Dasgupta advocates an η, or elasticity of marginal utility of income, in the range of 2 to 4 (and advocates, as well, the income transfers that would result from that elasticity in a non-Negishi world).

By including discounting over time as well as Negishi weights, welfare optimizing IAMs accept the diminishing marginal utility of income for intergenerational choices, but reject the same principle in the contemporary, interregional context. Some justification is required if different rules are to be applied in optimizing welfare across space than those used when optimizing welfare across time. At the very least, a climate-economics model's ethical implications should be transparent to the end users of its analyses. While ethical concerns surrounding discounting have achieved some attention in policy circles, the highly technical but ethically crucial Negishi weights are virtually unknown outside the rarified habitat of integrated assessment modelers and theoretical welfare economists. The Negishi procedure conceals one strong, controversial assumption about welfare maximization, namely that existing regional inequalities are not legitimate grounds for shifting costs to wealthier regions, but inequalities across time are legitimate grounds for shifting costs to wealthier generations. Other assumptions, needless to say, could be considered.

IV. Abatement costs and the endogeneity of technological change

The analysis of abatement costs and technological change is crucial to any projection of future climate policies. An unrealistic picture of fixed, predictable technological change, independent of public policy, is often assumed in IAMs – as is the treatment of investment in abatement as a pure loss. These choices are mathematically convenient, but prevent analysis of policies to promote and accelerate the creation of new, low-carbon technologies. This oversimplification supports the questionable conclusion that the best policy is to avoid immediate, proactive abatement, and wait for automatic technical progress to reduce future abatement costs.

[13] Earlier versions of PAGE2002, in fact, applied equity weights that boost the relative importance of outcomes in developing countries; the Stern Review modeling effort dropped the equity weights in favor of a more explicit discussion of regional inequality (Chris Hope, personal communication, 2008).

Choices in modeling abatement technology

There have been rapid advances in recent years in the area of modeling endogenous technological change. A review by the Innovation Modeling Comparison Project (Edenhofer, Lessmann, Kemfert *et al.* 2006; Grubb *et al.* 2006; Köhler *et al.* 2006) offers a very thorough description of the most recent attempts to model endogeneity and induced technological innovation – an effort that we will not attempt to reproduce here. Instead, this section briefly discusses three choices that all IAM modelers must make with regard to their representation of abatement technology: how to model increasing returns; how much technological detail to model; and how to model macroeconomic feedback.

Many models, especially general equilibrium models, assume technologies are characterized by decreasing returns to scale (meaning that doubling all inputs yields less than twice as much output), a provision which ensures that there is only one, unique equilibrium result. The assumption of decreasing returns may be realistic for resource-based industries such as agriculture or mining, but it is clearly inappropriate to many new, knowledge-based technologies – and indeed, it is inappropriate to many branches of old as well as new manufacturing, where bigger is better for efficiency, up to a point. Some industries exhibit not only increasing returns in production, but also "network economies" in consumption – the more people that are using a communications network or a computer operating system, the more valuable that network or operating system is to the next user.

The problem for modeling is that increasing returns and network economies introduce path dependence and multiple equilibria into the set of possible solutions. Small events and early policy choices may decide which of the possible paths or output mixes the model will identify as "the solution". An inferior computer operating system, energy technology, or other choice may become "locked in" – the established standard is so widely used, and so low-priced because it is produced on such a large scale, that there is no way for individual market choices to lead to a switch to a technologically superior alternative. Modeling increasing returns, path dependence, and multiple equilibria can bring IAMs closer to a realistic portrayal of the structure and nature of emissions abatement and economic development options, but at the expense of making models more difficult to construct and model results more difficult to interpret.

Knowledge spillovers are also related to increasing returns. Some of the returns to research and development are externalities, that is, they impact on third parties – other companies, industries, or countries. Because of the public goods character of knowledge, its returns cannot be completely appropriated by private investors. Without public incentives for research and development, private firms will tend to under-invest in knowledge, with the result that the total amount of research and development that occurs is less than would be socially optimal.
Increasing returns are modeled either as a stock of knowledge capital that becomes an argument in the production function, or as learning curves that lower technological costs as cumulative investments in physical capital or research and development grow.

A second choice that IAM modelers must make is how much technological detail to include. This encompasses not only whether to model increasing returns but also how many regions, industries, fuels, abatement technologies, or end uses to include in a model. A more detailed technology sector can improve model accuracy but there are limits to the returns from adding detail – at some point, data requirements, spurious precision, and loss of transparency begin to detract from a model's usefulness. On the other hand, a failure to model sufficient technological diversity can skew model results. Abatement options such as renewable energy resources, energy efficiency technologies, and behavioral shifts serve to limit abatement costs; models without adequate range of abatement options can exaggerate the cost of abatement, and therefore recommend less abatement effort, than a more complete model would.

The final modeling choice is how to portray macroeconomic feedback from abatement to economic productivity. A common approach is to treat abatement costs as a pure loss of income, a practice that is challenged by new models of endogenous technological change, but still employed in a number of IAMs, such as DICE-2007 (Nordhaus 2008). Two concerns seem of particular importance. Modeling abatement costs as a dead-weight loss implies that there are no "good costs" – that all money spent on abatement is giving up something valuable and thereby diminishing human welfare. But many costs do not fit this pattern: money spent wisely can provide jobs or otherwise raise income, and can build newer, more efficient capital. A related issue is the decision to model abatement costs as losses to income. Abatement costs more closely resemble additions to capital, rather than subtractions from income. (A similar argument can be made regarding many kinds of damage costs: see the earlier section on projecting future damages.)

Cost minimization models

Many of the IAMs making the most successful inroads into modeling endogenous technological change are cost minimization models. All four of the cost minimization models reviewed in this study – GET-FL (Hedenus *et al.* 2006), DNE21+ (Sano *et al.* 2006), MIND (Edenhofer, Lessmann and Bauer 2006), and MESSAGE-MACRO (Rao *et al.* 2006) – include learning curves for specific technologies and a detailed rendering of alternative abatement technologies.

GET-FL, DNE21+, MIND, and MESSAGE-MACRO are all energy systems models that include greenhouse gas emissions but not climate change damages. These models include various carbon-free abatement technologies, carbon capture and storage, and spillovers within clusters of technologies. GET-FL has learning curves for energy conversion and investment costs. DNE21+ has learning curves for several kinds of renewable energy sources and a capital structure for renewables that is organized in vintages. Both MIND and MESSAGE-MACRO combine an energy system model with a macroeconomic model. MIND has learning curves for renewable energy and resource extraction research; development investments in labor productivity; trade-offs between different types of research and development investment; and a vintaged capital structure for renewables and carbon capture and storage technologies. MESSAGE-MACRO models interdependencies from resource extraction, imports and exports, conversion, transport and distribution to end-use services; declining costs in extraction and production; and learning curves for several energy technologies (Edenhofer, Lessmann, Kemfert *et al.* 2006; Köhler *et al.* 2006).

These energy system models demonstrate the potential for representing induced innovation and endogeneity in technological change. Unfortunately, the very fact of their incredible detail of energy resources, technologies and end uses leads to a separate problem of unmanageably large and effectively opaque results in the most complex IAMs. (For example, the RITE Institute's DNE21+ models historical vintages, eight primary energy sources and four end-use energy sectors, along with five carbon capture and storage methods, several energy conversion technologies, and separate learning curves for technologies like wind, photovoltaics and fuel cells.) A model is constructed at the level of detail achievable from present day energy sector data, providing accuracy in the base year calculations. Then the model is extended into the future based on unknowable and untestable projections, turning historical accuracy into spurious precision in future forecasts. A high level of specificity about the future of the energy sector cannot be sustained over the number of years or decades necessary to analyze the slow, but inexorable, advance of climate change.

VI. Conclusions

The best-known climate-economics models weigh the costs of allowing climate change to continue against the costs of stopping or slowing it, and thus recommend a "best" course of action: one that, given the assumptions of the model, would cause the least harm. The results of such models are, of course, only as good as their underlying structures and parameter values.

Analysis of climate change, in economics as well as in science, inescapably involves extrapolation into the future. To understand and respond to the expected changes, it is essential to forecast what will happen at greenhouse gas concentrations and temperature levels that are outside the range of human experience, under regimes of technological progress and institutional evolution that have not yet even been envisioned. While some progress has been made toward a consensus about climate science modeling, there is much less agreement about the economic and societal laws and patterns that will govern future development.

IAMs seek to represent both the impacts of changing temperature, sea level, and weather on human livelihoods, and the effects of public policy decisions and economic growth on greenhouse gas emissions. IAMs strive not only to predict future economic conditions but also to portray how we value the lives, livelihoods, and natural ecosystems of future generations – how human society feels about those who will inherit that future. The results of economic models depend on theories about future economic growth and technological change, and on ethical and political judgments.

Model results are driven by conjectures and assumptions that do not rest on empirical data and often cannot be tested against data until after the fact. To the extent that climate policy relies on the recommendations of IAMs, it is built on what looks like a "black box" to all but a handful of researchers. Better-informed climate policy decisions might be possible if the effects of controversial economic assumptions and judgments were visible, and were subjected to sensitivity analyses.

Our review of the literature has led to several concrete lessons for model development:

- **Many value-laden technical assumptions are crucial to policy implications, and should be visible for debate. Existing models often bury assumptions deep in computer code and parameter choices, discouraging discussion. Ultimately, results are often driven by these core assumptions, rather than by the technical apparatus.**

- **Crucial scientific questions – like the value of the climate sensitivity parameter and the threshold and probability for huge, irreversible catastrophe – remain uncertain. Most IAMs use central or average estimates, and ignore catastrophic risk. Those few that use Monte Carlo analysis often truncate distributions, de-emphasizing or excluding low-probability, high-cost outcomes. A broader embrace of the full range of uncertainty is required, and will likely lead to different results.**

- **Modeling climate economics requires the projection of damages at temperatures outside the historical experience. Many models arbitrarily assume that damages grow as the square of temperature change, calibrated to one or two speculative point estimates of low-temperature damages. Almost all models treat climate damages as losses of current income rather than decreases in capital stock. Alternative assumptions, which are at least as plausible, would lead to much greater estimates of damages, and more urgency about policies to address the problem.**

- **Today's actions affect the climate and economy of future generations, thus linking current and future welfare. Many models have high discount rates, inflating the importance of short-term abatement costs while trivializing long-term benefits of mitigation. A positive rate of pure time preference is common but controversial. As is widely recognized, a lower discount rate values the future more fully, and justifies an "optimal" policy of doing more, sooner, to mitigate climate change.**

- Climate choices occur in an unequal world and inevitably affect opportunities for development. Most regionally disaggregated models use a technical device ("Negishi welfare weights") that freezes the current income distribution, constraining models to ignore the welfare benefits of movement toward inter-regional equality. Without this artificial limitation, modeling of climate and development would place much greater weight on the impacts on low-income regions.

- Measures to induce or accelerate technological change will be crucial for a successful climate policy. Many IAMs model decreasing returns or assume that technological progress is exogenous, and treat abatement costs as an unproductive loss of income, not an investment in energy-conserving capital. Models of endogenous technical change and increasing returns are more complex but more realistic, allowing path dependence and multiple equilibria.

This review has highlighted several of the key shortcomings typically found in many of the climate-economics models that are currently being used to inform climate policy. The models have improved over the years, including expanded treatment of externalities, technological innovation, and regional disaggregation. But there is still tremendous scope for further improvement, including more extensive sensitivity analyses and more rigorous examination of risk and uncertainty. And fundamentally subjective judgments, especially those that embody deeply value-laden assumptions, can be made more explicit.

What difference would it make to change these features of climate economics modeling? In the absence of a better model, we can only speculate about the results. Our guess is that the modifications we have proposed would make a climate economics model more consistent with the broad outlines of climate science models, portraying the growing seriousness of the problem, the ominous risks of catastrophe, and the need for immediate action.

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EXHIBIT B TO COMMENTS OF CALIFORNIA AND CONNECTICUT ATTORNEYS GENERAL ON ADVANCE NOTICE OF PUBLIC RULEMAKING, DOCKET ID NO. EPA- HQ-OAR-2008-0318

MEMORANDUM OF UNDERSTANDING BETWEEN THE ATTORNEY GENERAL OF THE STATE OF CALIFORNIA AND THE SAN DIEGO COUNTY REGIONAL AIRPORT AUTHORITY REGARDING THE SAN DIEGO INTERNATIONAL AIRPORT MASTER PLAN

THIS MEMORANDUM OF UNDERSTANDING ("MOU") is made by and between the San Diego County Regional Airport Authority ("Authority") and Edmund G. Brown Jr., Attorney General of the State of California, acting in his independent capacity on behalf of the People of the State of California ("Attorney General"), collectively referred to herein as the "parties," based on the following facts and considerations:

WHEREAS, the Authority and the Attorney General mutually desire that future operations at the San Diego International Airport ("Airport") over which the Authority has jurisdiction be conducted in a manner which reduces greenhouse gas ("GHG") emissions that otherwise might occur; and

WHEREAS, pursuant to the San Diego Regional Airport Authority Act, Public Utility Code Sec. 170000 et seq., the Authority is responsible for the operation, maintenance and improvement of the Airport; and

WHEREAS, the Authority has been engaged for over four years in studying a variety of means to maintain and improve the Airport so that it may remain a strong contributor to the economy of the region, including public outreach and collaboration with various local, regional and state agencies; and

WHEREAS, based on that effort, the Authority staff identified a number of actions that might be beneficial to its mission, and incorporated those possible actions into a draft Airport Master Plan ("Draft AMP"); and

WHEREAS, pursuant to the California Environmental Quality Act and Guidelines ("CEQA"), the Authority prepared and on May 31, 2006 circulated for a 150-day public/agency review and comment period a Draft Environmental Impact Report ("May 2006 DEIR") for the Draft AMP; and

WHEREAS, as a result of the public comments received on the May 2006 DEIR, the Authority elected to broaden the scope of the May 2006 DEIR to consider the potential environmental effects of the Draft AMP that might occur through the year 2030; and

WHEREAS, the Authority so revised the May 2006 DEIR, and released the revised version October 2, 2007 ("October 2007 DEIR"), and announced that the public review and comment period on the October 2007 DEIR would extend to November 30, 2007; and

WHEREAS, at the request of a number of public agencies and community groups, the Authority twice extended the November 30, 2007 public comment period deadline on the October 2007 DEIR, first to January 4, 2008 and then to February 4, 2007; and

WHEREAS, in recognition of the new regulatory environment and reflecting the Authority's commitment to full disclosure of the AMP's environmental impacts, the October 2007 DEIR included a new section discussing and analyzing the existing GHG emissions from the operation of the Airport, and the GHG emissions that are likely to result from future growth in air travel to and from the Airport; and

WHEREAS, the Authority desires to ensure the environmental review process for the Draft AMP is completed in a timely manner and that litigation between the parties is avoided; and

WHEREAS, the Authority consistently is proactive in addressing environmental concerns before statutes or regulations have been adopted to impose specific controls or requirements, as evidenced by its Sustainability Policy and other Authority programs; and

WHEREAS, the Attorney General of the State of California serves as the chief law officer of California and in that capacity, is charged with enforcing the laws safeguarding the State's environmental and natural resources; and

WHEREAS, the Attorney General is committed to the successful implementation of AB 32 and reducing GHG emissions throughout California; and

WHEREAS, the Attorney General believes that, as reflected in the latest reports of the Intergovernmental Panel on Climate Change, global warming presents profoundly serious challenges to California and the nation, and that actions taken now and in the next few years with respect to assessing and limiting GHG emissions will determine our future; and

WHEREAS, no existing regulations govern GHG emissions from aircraft, although, in December 2007, the Attorney General petitioned the Environmental Protection Agency to undertake a rulemaking under the Clean Air Act to propose and adopt regulations setting emissions standards to control and limit GHG emissions from aircraft; and

WHEREAS, the Parties recognize that although under state law the Authority is responsible for managing the Airport, federal law imposes certain limitations on the Authority, including its use of airport revenue and its authority to regulate the activities of air carriers and the operation of aircraft; and

WHEREAS, after conducting a series of workshops and receiving public testimony, the Authority adopted a Sustainability Policy on February 7, 2008 which will serve as the foundation for a sustainable growth strategy which commits the Authority to implement practices that will allow it to meet the transportation and other needs of the present generations without compromising the environment for the benefit of future generations; and

WHEREAS, the Attorney General and the Authority desire to enter into this MOU in recognition of the mutual commitment of the Attorney General and the Authority to ensure meaningful and constructive consideration of GHG emissions and actions to reduce such emissions, and in light of the Authority's forward-looking and ground-breaking commitment to protect the environment as evidenced by its Sustainability Policy and by entering into this MOU; and

WHEREAS, the Authority intends to work collaboratively with other airports in the State of California and with airlines, directly and through the Air Transport Association, to facilitate implementation of measures to address GHG emissions related to airports (including those set forth in this MOU) in a consistent, cost-effective manner.

NOW, THEREFORE, in consideration of the mutual terms, covenants and conditions, the Authority and the Attorney General enter into and agree to this Memorandum of Understanding:

Section 1. Implementation of Specific Measures to Control GHG Emissions.

1. Specific Measures. In accordance with this MOU the Authority will implement the specific measures described more fully in Exhibit A to limit the GHG emissions generated by the operation of the Airport, and particularly the implementation of the AMP ("Specific Measures"), following these principles:

    a. Specific Measures will be implemented in a manner that does not disrupt the on-going operations of the Airport; violate federal law, regulations, or an FAA policy or rule published in the Federal Register after an opportunity for public notice and comment; interfere with the directions or instructions of an FAA air traffic controller; or compromise the safety of the traveling public, the airport, or aircraft. If the Airport believes that a Specific Measure cannot be implemented consistent with this provision, than it shall notify the Attorney General, and the parties shall confer in good faith.

b. Subject to the other applicable provisions of this MOU, each Specific Measure shall be implemented to the extent that such measure produces a meaningful net reduction in GHG emissions that otherwise would result from the construction of the AMP or operations at the Airport. If the Airport believes that a Specific Measure will not produce a meaningful net reduction in GHG emissions, it shall notify the Attorney General, and the parties shall confer in good faith. The parties shall seek to agree upon an alternative or modified Specific Measure that achieves a meaningful net reduction in GHG emissions for approximately the same cost to the Authority as the original measure. Alternatively, by mutual agreement, a Specific Measure may be omitted.

2. Cooperation with Regulatory Agencies. The Attorney General and the Authority recognize that the implementation of the AMP and the terms of the MOU, including the Specific Measures, will require the approval and cooperation of federal, state, regional and local agencies, and therefore agree to cooperate in the implementation of the MOU so that its benefits might be attained, including, as necessary, adjustments to specific details of the implementation of the Specific Measures to meet the statutory or regulatory requirements imposed by such agencies, acting within the respective authority of each, which adjustments shall be embodied in a writing signed by both parties.

Section 2. Covenant Not to Sue or Otherwise Challenge the AMP EIR.

1. Covenant Not to Sue. In consideration of the Authority's commitment to implement the Specific Measures, and subject to Section 2.2, the Attorney General agrees that it will not make any comment on, file a legal challenge against, or otherwise intervene against the Authority in any suit challenging the adequacy of the EIR for the AMP, including the adequacy of mitigation measures identified in the EIR. Notwithstanding the preceding, the Attorney General does not waive any right to file an *amicus curiae* brief in a state or federal appellate court that addresses the legal requirements of CEQA or any other state or federal law. In the event the Attorney General files such a brief, it will expressly not take a position on the legal adequacy of the EIR. This section shall not restrict any constitutional or statutory obligation of the Attorney General, upon the request of a state agency, board, or commission, to represent such agency, board or commission as a client.

2. Termination of MOU in Event of Other Agency Litigation. In the event litigation is timely commenced by any public agency, including an agency for which the Attorney General is acting as counsel, that

challenges the adequacy of the EIR for the AMP or mitigation measures identified in the EIR, the Authority shall have the right to terminate the MOU, subject to the following conditions:

a. Within 30 days after the litigation is commenced, the Authority shall send written notice to the Attorney General that it is considering exercising its right to terminate this MOU;

b. Within 10 days after receiving such notice, the parties shall meet and confer;

c. Within 45 days after the litigation is commenced, or longer with the Attorney General's written consent to extend this period, the Authority shall serve a notice on the Attorney General of its election to terminate the agreement; and

d. If the Authority so elects to terminate this MOU, the Authority shall not assert any statute of limitations or laches against the Attorney General to prevent the Attorney General from pursuing any claim or remedy it might have had at the time the MOU entered into effect, so long as it files such action within thirty days after receiving notice of termination of the MOU.

e. If the Authority so elects to terminate this MOU, the Authority shall have no obligations whatsoever under this MOU except for the obligation set forth in the previous subsection (2.2.d).

Section 3. Dispute Resolution.

1. Good Faith Efforts to Resolve Disputes. The parties shall attempt in good faith to resolve any controversy or claim arising out of or relating to this MOU. If a controversy or claim should arise that cannot be resolved by the respective staffs, the President, or delegate, of the Authority and the Attorney General's delegate, (collectively, the "Representatives") will meet at least once in person and, in addition, at least once in person or by telephone to attempt to resolve the matter. The Representatives will make every effort to meet as soon as reasonably possible at a mutually agreed time and place.

2. Modifications. No addition to or modification of any term or provision of this MOU will be effective unless set forth in writing and signed by an authorized representative of each party.

Section 4. Compliance with Law. The parties recognize that their respective commitments and covenants are subject to applicable requirements of law, including those identified in this Section 4.

1. CEQA. It is the parties' good faith belief that this MOU does not constitute a project within the meaning of CEQA and its Guidelines. The implementation of specific measures described in this MOU shall be subject to review and approval pursuant to the requirements of CEQA and its Guidelines.

2. Federal Limitations on Use of Airport Revenue. The parties to this MOU have considered the provisions of the Federal Aviation Administration (hereinafter "FAA") 1999 Policy and Procedure Concerning the Use of Airport Revenue [64 Fed. Reg. 7696, dated Feb. 16, 1999]; the Airport and Airway Improvement Act of 1982 ("AAIA"), codified at 49 U.S.C. §47107(b); the Federal Aviation Administration Authorization Act of 1994, P.L. 103-305 (Aug. 23, 1994); the Airport Revenue Protection Act of 1996, Title VIII of the Federal Aviation Administration Act of 1996, P.L. 104-264 (Oct. 9, 1996), 110 Stat. 3269 (Oct. 9, 1996); 49 U.S.C. §46301(a)(3); and 49 U.S.C. §47133.

   The parties further have considered that the Authority has received numerous federal Airport Improvement Project ("AIP") grants over the years and that a condition to receiving federal grant funds is the following grant assurance Number 25: "All revenues generated by the airport . . . will be expended by it for the capital or operating costs of the airport; the local airport system; or other local facilities which are owned or operated by the owner or operator of the airport and which are directly and substantially related to the actual air transportation of passengers or property; or for noise mitigation purposes on or off the airport."

   The parties have considered these provisions, and enter into this MOU with the good faith belief that this MOU may be implemented in compliance with those policies, statutes, and assurances.

   Compliance with Federal Rates and Charges Policy. The parties have considered the FAA's Policy Regarding Airport Rates and Charges, 61 Fed. Reg. 31994, dated June 21, 1996, a policy adopted pursuant to the Federal Aviation Administration Authorization Act of 1994, P.L. 103-305 (Aug. 23, 1994), 49 U.S.C. §47129. The parties have considered these provisions, and enter into this MOU with the good faith belief that this MOU may be implemented in compliance with such policy.

3. Effect of MOU on Future Boards. Except as expressly stated herein, nothing in this MOU shall be construed as a waiver of any party's discretionary authority or deemed to restrict authority granted to any

party under law in any way with respect to future legislative, administrative or other actions, including but not limited to those actions related to the AMP.

Section 5. Effectiveness

This MOU shall become effective upon the final approval of both the Attorney General and the Board of the Authority, and the execution of the MOU.

Section 6. No Admissions

Neither this MOU nor any of its terms or provisions, nor any of the negotiations or proceedings connected with it, shall be asserted to constitute or be construed as an admission or concession by either party of any fact or legal assertion.

Section 7. General Terms and Conditions.

1. Public Announcement. Upon final approval and execution of the MOU by both the Attorney General and the Authority, the parties shall simultaneously make available to the public the terms of this MOU.

2. Time of Performance. The actions necessary to achieve the objectives of this MOU shall be completed in a timely manner.

3. Full Cooperation. The Authority and the Attorney General agree to cooperate with each other and to provide each other with all necessary documents (subject to any privileges or other legal restrictions that may apply) when requested. Each party will use its best efforts to achieve the objectives of this MOU, consistent with its legal obligations and applicable law.

4. Independent Capacity. The Attorney General enters into this MOU in his independent capacity and not on behalf of any other state agency, commission, or board. Nothing in this MOU restricts any constitutional or statutory obligation of the Attorney General, upon the request of a state agency, board, or commission, to represent such agency, board or commission as a client.

   Recognition of Financial Limitations. The parties acknowledge that the Authority is not a tax supported public entity and that its source of funds is limited to airport revenues, federal AIP grants and Passenger Facility Charges. They also acknowledge that the federal AIP grants and Passenger Facilities Charges are subject to, among other things, Congressional control and FAA administrative discretion. The parties have considered this, and enter into this MOU with the good faith belief that this MOU may be implemented in compliance with any restrictions on the Authority's use of airport revenues, federal AIP grants, and Passenger Facility Charges.

5. Notice. Any notice required or permitted by this MOU shall be in writing and shall be delivered as follows with notice deemed given as indicated: (a) by personal delivery when delivered personally, (b) by overnight courier upon written verification of receipt, or (c) by certified or registered mail, return receipt requested, upon verification of receipt. Notice shall be sent to the addresses set forth below, or such other address as either party may specify in writing:

If to the Authority:

Thella F. Bowens, President/CEO
San Diego County Regional Airport Authority
P.O.82776
San Diego, CA 92138-2776
Tel.: (619) 400-2444; FAX: (619) 400-2448

If to the Attorney General:

Deputy Attorney General Susan Durbin
Deputy Attorney General
1300 I Street
Sacramento, CA 95814
Tel.: (916) 324-5475; FAX: (916) 322-5609

6. Enforceability. The parties desire to ensure the terms of this MOU are completed as described herein. Neither party shall be liable to the other for any claimed costs or damages arising from a claimed non-performance of any provision of this MOU.

7. Partial Invalidity. If any term, covenant, condition, or provision of this MOU is held by a court of competent jurisdiction to be invalid, void or unenforceable, the remainder shall remain in full force and effect, and shall in no way be affected, impaired or invalidated.

8. California Law. This MOU shall be governed by and construed in accordance with the laws of the State of California.

9. Rule of Construction. This MOU shall be deemed to have been jointly drafted, so that the general rule of construction that it be construed against the drafter shall not apply.

10. <u>Signatures.</u> This MOU may be executed in counterparts, each of which shall be deemed an original. This MOU shall be binding upon the receipt of original or electronic signatures.

11. <u>Entire Agreement.</u> This MOU represents the entire agreement of the parties with respect to the subject matter herein, and supersedes any prior written or oral representations, discussions, or understandings between the parties relating to the subject matter of this MOU.

The undersigned have read this Memorandum of Understanding, fully understand its contents, and by the signatures below agree to its terms on behalf of their respective public agencies.

SAN DIEGO COUNTY REGIONAL AIRPORT AUTHORITY

By: ________________________
Thella F. Bowens
President and CEO

ATTORNEY GENERAL, STATE OF CALIFORNIA

By: ________________________
Edmund G. Brown Jr.
Attorney General

APPROVED AS TO LEGAL FORM

By: ________________________
Breton K. Lobner
General Counsel

MAY 5 2008

EXHIBIT A
SPECIFIC MEASURES

1. Reduction in Aircraft On-the-Ground Energy Usage.

   a. Landside Power and Preconditioned Air at All New Gates. All new gates constructed under the Master Plan will provide landside power and preconditioned air to aircraft at such gates. The Authority will operate those new gates so as to make such power and preconditioned air available to aircraft at such gates. Prior to constructing the new gates, the Authority will ask airlines that will use the new gates to submit any specific requests as to how landside power and preconditioned air facilities are designed and provided, to increase the utility of such facilities to the airlines. The Airport will make reasonable efforts to accommodate the requests.

   b. Retrofit Existing Gates with Landside Power and Preconditioned Air. As the Airport or its tenant reconditions or refurbishes existing gates, it will retrofit such existing gates as do not already provide landside power and preconditioned air to aircraft at the gate to provide such power. The Authority will operate those reconditioned or refurbished gates so as to make such power and preconditioned air available to aircraft at such gates. Prior to refurbishing existing gates, the Authority will ask airlines that will use the gates to submit any specific requests as to how landside power and preconditioned air facilities are designed and provided, to increase the utility of such facilities to the airlines. The Airport will make reasonable efforts to accommodate the requests.

   c. Provision of Landside Power at All New Cargo Facilities and Hangars. All new cargo facilities and hangars constructed under the AMP will be equipped to provide electrical power to aircraft at such facilities and hangars. The Authority will operate its new cargo facilities and hangars and cause others that construct new cargo facilities and hangars to operate them to make such power available to aircraft at such cargo facilities and hangars.

   d. Retrofit All Existing Cargo Facilities and Hangars with Landside Power. As the Airport or its tenants recondition or refurbish existing cargo facilities and hangars, the Airport will require retrofitting all such cargo facilities or hangars to provide landside power to aircraft at such cargo facilities or hangars. The Authority will operate its reconditioned or refurbished cargo facilities or hangars and cause others that recondition or retrofit cargo facilities and hangars to operate them so as to make such power available to aircraft at such cargo facilities or hangars.

e. Cargo and General Aviation Aircraft Use of Landside Power. As the Airport or its tenant reconditions or refurbishes existing gates at its cargo and general aviation facilities, it will retrofit such existing gates as do not already provide landside power and preconditioned air to aircraft at the gate to provide such power. The Authority will operate those reconditioned or refurbished gates so as to make such power and preconditioned air available to aircraft at such gates. Prior to refurbishing existing gates, the Authority will ask airlines that will use the gates to submit any specific requests as to how landside power and preconditioned air facilities are designed and provided, to increase the utility of such facilities to the airlines. The Airport will make reasonable efforts to accommodate the requests.

f. Aircraft Movements. The Authority will prepare an inventory of those greenhouse gas emissions attributable to the movement of aircraft at the Airport that it expects in 2010. The Authority will then establish a goal to reduce, by 2015 and with due regard to regulations to be issued pursuant to AB 32, annual GHG emissions levels by an amount equivalent to 20% of the emissions in 2010 from the movement of aircraft. Toward that end, by January 1, 2010, the Authority will prepare and make available to the public a study, with or without the participation of the airlines and the FAA, to identify and evaluate techniques to reduce fuel consumption and GHG emissions during all stages of aircraft movements at the Airport. The study shall recommend specific measures to achieve such reductions, based on an assessment of technical, economic, environmental and safety issues associated with the measures. The Authority will then investigate and attempt to implement meaningful incentives or other programs to encourage the use of those measures that were studied and recommended for implementation.

2. Reduction of Landside Energy Usage

a. Replacement of Existing Tow Vehicles With Electric or Alternative Fuel Aircraft Pushback Tractors.

i. Beginning January 1, 2010, the Airport will replace all existing aircraft pushback tractors it currently owns with electric or alternative fuel vehicles upon the completion of the useful life of such existing vehicles, to the extent such vehicles are commercially available. Prior to January 1, 2010, the Airport will continue to replace tow vehicles in the ordinary course, consistent with its past purchasing practices. As used in this MOU, "alternative fuel vehicle" means a vehicle that runs on an energy source, fuel or blend of fuels that achieves a reduction of at least 10 percent carbon intensity relative to petroleum fuel, as contained in Governor Schwarzenegger's Executive Order S-01-07.

ii. Beginning January 1, 2010, the Airport will require every airline or other tenant or service provider to replace all existing aircraft pushback tractors which such airline, tenant or service provider currently owns or operates with electric or alternative fuel vehicles upon the completion of the useful life of such existing vehicles, to the extent permitted by federal law and to the extent such vehicles are commercially available.

iii. Should such alternative fuel vehicles not be commercially, and reasonably, available, the parties shall confer in good faith to negotiate a deferral of this provision until such time as the vehicles are so available.

b. Replacement of Shuttles with Electric or Alternative Fuel Vehicles. The Airport will implement one of the following alternatives at its discretion:

i. By January 1, 2010, before the first elements of the AMP construction will be placed into service, the Airport will implement an incentive-based program to induce every operator of a shuttle service (e.g., hotel, door-to-door, parking) on the Airport to replace its existing shuttle vehicles which such operator at that time owns or operates with electric or alternative fuel shuttle vehicles upon the completion of the useful life of such existing shuttle vehicles.

ii. As an alternative to such an incentive-based program, by January 1, 2010, the Airport shall impose a requirement on every operator of a shuttle service on the Airport to replace its existing shuttle vehicles which such operator then owns or operates with electric or alternative fuel shuttle vehicles in accordance with the following provisions, to the extent permitted by federal law:

1. Operators that own and operate from 1 to 3 shuttles shall replace all existing vehicles by January 1, 2015.

2. Operators that own and operate 4 or more shuttles:

a. January 1, 2012: 25 % of existing vehicles.

b. January 1, 2013: 50% of existing vehicles.

c. January 1, 2014: 75% of existing vehicles.

d. January 1, 2015: 100% of existing vehicles.

iii. Implementation of either of these alternative measures shall be subject to the Authority's determination of commercial availability of equipment and adequate refueling infrastructure. If the Authority determines that such equipment is not commercially available or that there is not an adequate refueling infrastructure, then it shall provide a contemporaneous detailed, written statement of the reasons for that determination to the Attorney General, which can be made available to the public.

iv. The Authority shall make reasonable good faith efforts to assist shuttle operators to obtain grant funding or other concessionary financing that would enable such operators to replace existing vehicles more rapidly than is contemplated by the above schedules.

3. <u>Use of Green Materials and Sustainable Design</u>

a. <u>Use of Cool Roofs (or Solar Panels) and Cool Pavements</u>. The Authority will incorporate into AMP construction, to the extent feasible, including reasonable commercial availability of materials, the use of cool roofs (or rooftop solar panels) on all new buildings, and construct cool pavements for newly constructed paved or rebuilt paved areas that carry traffic, to the extent permitted by federal law and state contracting law.

i. The Authority currently estimates that it will be feasible for approximately 80% of the pavement that is part of the AMP to be constructed as cool pavement. If the Authority determines that less than such percentage can be constructed as cool pavement, it will provide a contemporaneous detailed, written statement of the reasons for that determination to the Attorney General, which can be made available to the public.

ii. The Authority currently intends to specify that all of the roofs under the AMP should be constructed as cool roofs. If the Authority determines that some of the roofs or portions thereof cannot be constructed as cool roofs, it will provide a contemporaneous detailed, written statement of the reasons for that determination to the Attorney General, which can be made available to the public.

b. Construct All New Facilities to Meet LEED Certification (or equivalent), With a Target of Silver or Better. The Authority will seek to have all new terminal buildings constructed under the AMP achieve LEED certification with a target of Silver or better (or equivalent certification from a different certifying entity) to the extent feasible and to the extent permitted by federal law and state contracting law. This requirement shall not apply to facilities under the control of the United States Government. As to hangars or warehouses, if special LEED (or equivalent) procedures and standards are adopted to apply to such structures at airports, then the Authority will seek to have such structures achieve LEED certification with a target of Silver or better (or equivalent certification from a different certifying entity) or better, to the extent feasible and to the extent permitted by federal law and state contracting law.

4. Use of Green Construction Methods and Equipment.

a. Use of Construction Equipment Running on Alternative Fuels or Particulate Traps. The Authority will require that firms performing AMP construction use equipment that either runs on alternative fuels or employs ARB-certified particulate traps, to the extent permitted by federal law and state contracting law, for construction projects for which the Authority determines that such equipment is commercially available. If the Authority determines that it will not require use of such construction equipment, it will provide a detailed, written statement of the reasons for that determination to the Attorney General, which can be made available to the public. In such event, the Authority also will impose a limitation of five minutes on idling of such equipment.

5. Coordination and Encouragement of Tenants to Address GHG

a. Recycling. The Authority will continue to expand its existing aggressive recycling program for which it has been recognized by US EPA for its accomplishments, and named as Recycler of the Year by the City of San Diego for the last 5 years. These programs extend to the Airport, all tenants, businesses and concessions operating at the Airport and, to the extent permitted by federal law, all airlines.

b. Sale of Unleaded Mogas. The Authority will encourage the present operator of the general aviation facility to offer mogas for those planes that can run on unleaded mogas. When the Authority undertakes a process for seeking new operator(s) of general aviation services, it will include as a requirement that such operator(s) offer unleaded mogas.

c. Reduction of Carbon Footprint. In implementing its Sustainability Policy, the Authority will work with all tenants, businesses, and concessions operating at the Airport to reduce their carbon footprints.