Comments on EPA and NHTSA "Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards"

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My comments address section III.H.6, Federal Register[1] pages 49611 – 49618, in which EPA and NHTSA assign a monetary value to the benefits of reducing greenhouse gas (GHG) emissions. That section develops "interim" estimates of the social cost of carbon (SCC), or monetary value of the damages resulting from an incremental ton of CO_2 emissions. The interim SCC estimates range from $5 to $56 in 2007, depending on assumptions about discounting, and grow at 3 percent annually in subsequent years.

I will demonstrate that the methods used to develop these estimates rely on a biased and incomplete reading of the economic literature on climate change. The methodology used to estimate interim SCC values expresses an unexplained confidence in a handful of authors and models, and offers arbitrary, unsupported judgments as grounds for ignoring important alternatives. In several cases the underlying data and analyses cited in the proposed rulemaking appear to have been misread or misquoted, since they do not actually support the conclusions drawn from them. Most of the errors, omissions, and arbitrary judgments in section III.H.6 tend to reduce the estimate of the SCC; thus a corrected version of the same calculations would result in a larger SCC.

It is impossible to develop an adequate alternative estimate of the SCC from the information presented in this docket. Further research and analysis along the lines suggested in my comments will be needed to create a better estimate. As I will demonstrate, climate damages may be several times as large as the estimates used by EPA and NHTSA; the analysis of the discount rate presented here actually supports an initial discount rate of 2% or less; and there is a strong case in economic theory for discount rates that decline over time. Finally, the crucial question of catastrophic climate risk suggests a need for insurance-like policies to protect against worst-case outcomes, an approach that is quite distinct from cost-benefit analysis.

The EPA/NHTSA discussion of the SCC begins with several general observations that frame the analysis (Federal Register, 49611-49612). Some of the serious anticipated damages from climate change, such as loss of endangered species, cannot be quantified or monetized, so they are

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[1] All references to the Federal Register in these comments refer to vol. 74 no. 186, September 28, 2009; volume number and date are omitted in citations for the sake of brevity.

routinely omitted – implying that estimates of the SCC may be too low. Ethical judgments, including those involving the treatment of future generations, play a role in any calculation of the SCC. Since the problem of climate change is completely global, and climate protection is a global public good, the SCC should be based on global, not domestic, climate damages. These are important and valid observations – but they are only the prologue to the calculations.

Following that prologue, there are three stages in the calculations:

1. A process of "filtering" and weighting estimates from climate economics models (49612-49613);
2. An extended discussion of the choice of discount rates, and the resulting range of SCC estimates (49613-49616);
3. Four final "caveats" (49616-49617), of which the most important concerns the treatment of catastrophic risk.

My comments address each of these points in turn.

1. A narrow, arbitrary "filter" screens out most economic analyses of climate change

 The detailed discussion of the economics literature on the SCC begins by applying a filter to the existing estimates (Section III.H.6.b.ii is titled "Filtering Existing Analyses") – which has the effect of dismissing almost everything written on the subject. The filtering process includes several stages (all but the last are explicitly listed on page 49612):

a. Richard Tol's 2008 meta-analysis is taken as a starting point;
b. Attention is restricted to peer-reviewed studies;
c. Three specific integrated assessment models (IAMs), FUND, PAGE, and DICE are selected, while others are ignored.
d. An unstated corollary is that the default data sets developed by the authors of these three models are adopted without discussion.

Each step of this filtering process introduces arbitrary biases into the estimation process.

1.a. Tol's meta-analysis focuses heavily on Tol's own work

Tol's meta-analysis,[2] sometimes described as the most comprehensive available study, is in fact a highly personal view of the economics literature. Tol includes 211 estimates of the SCC, of which more than half, 112 to be exact, come from Tol's own work.[3] Disproportionate numbers also come from a few other authors and models. Every version of William Nordhaus' DICE

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[2] Richard Tol, "The Social Cost of Carbon: Trends, Outliers and Catastrophes," *Economics* (e-journal), Vol. 2, 2008.
[3] See Tol 2008, Table 2, for author counts.

model is included, despite the fact that the newer versions were created to update and replace the older versions.

Tol has not published 112 separate studies of the SCC; rather, he has counted multiple scenarios and sensitivity analyses within his own studies as separate estimates. He has extended the same treatment to some but not all other economists. For example, the Stern Review, which included multiple scenarios and sensitivity analyses, is treated as only generating a single estimate of the SCC in Tol's meta-analysis. Thus the use of Tol's meta-analysis as a starting point is not a neutral decision; it introduces biases in favor of the work of Tol and Nordhaus, and against the Stern Review, among others.

1.b. The Stern Review's path-breaking analysis of climate economics is excluded by the "peer review" criterion

Insisting on peer review as an absolute criterion for inclusion in the SCC process also creates a bias. In practice, a principal effect of the peer review criterion is to rule out consideration of the widely discussed Stern Review, which offered an innovative, rigorous analysis leading to a relatively high estimate of the SCC, $85 per ton of CO_2. Tol and some other economists have criticized the Stern Review for appearing as a government policy report rather than in a peer-reviewed journal. However, the level of professional review and detailed scrutiny applied to the Stern Review, both before and after its publication, was far beyond the normal peer review process for articles published in academic journals.

The credibility of the Stern Review as serious economic research appears to be beyond doubt. Nicholas Stern has served as the chief economist of the World Bank and as a top official in the British Treasury Department, as well as teaching economics at the London School of Economics. Following the publication of the Stern Review, the American Economics Association (AEA) published a symposium on it in the *Journal of Economic Literature*, and invited Stern to give the prestigious Ely Lecture at the AEA's annual meeting in 2008; that lecture was published in the *American Economic Review*, the highest-status journal in the field.[4] The Stern Review, described by one critic as a "radical report,"[5] was initially published in London by that notorious radical publisher, Her Majesty's Treasury, and later reprinted by Cambridge University Press.

The Stern Review and its high estimate of the SCC have played a major role in the development of climate policy in the UK. The complaints of a few economists about peer review should not be allowed to exclude the detailed, insightful analyses of the Stern Review from US policy deliberations.

1.c. FUND, PAGE, and DICE are not the only relevant climate economics models.

The methodology for developing interim SCC estimates simply asserts that

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[4] Nicholas Stern, "The Economics of Climate Change", *American Economic Review* (2008), 98:2, 1-37.
[5] Bjorn Lomborg, in *Cool It* (see Frank Ackerman, "Hot, It's Not: Reflections on *Cool It*, by Bjorn Lomborg," *Climatic Change* (2008) 89: 435-446).

> "…the Administration proposes to "filter" existing SCC estimates by using those that… are based on the most recent published version of each of ***the three major integrated assessment models***, FUND, PAGE, and DICE." (Federal Register, op. cit., 49612, emphasis added)

The decision to rely exclusively on these three models is supported only by the equally general and undocumented statement,

> "…the FUND, PAGE, and DICE models now stand as the most comprehensive and reliable efforts to measure the economic damages from climate change." (ibid., 49613)

No evidence is offered in support of the comprehensive or reliable nature of these three models; the reader must take it or leave it, on the personal authority of the authors of the proposed ruling. This judgment, however, is not universal – even within EPA. The EPA web page on "Climate Economic Modeling" (http://www.epa.gov/climate/climatechange/economics/modeling.html) opens with the statement

> "EPA uses a variety of economic models and analytical tools when conducting climate economic analyses. Below is a list of the specific models used by EPA…"

That list of specific models makes no mention of FUND, PAGE, or DICE, but describes the ADAGE model of the global economy (used for modeling climate policies, among other purposes), the MiniCAM integrated assessment model, and other modeling tools.

A recent literature review identifies and discusses 30 different climate economics models which have been used in the IAM literature in the last ten years.[6] Many of these models, from major university research groups and nonprofit research centers in the United States, Europe, and Japan, contain a wealth of features and details that are absent in FUND, PAGE, and DICE. Indeed, those three chosen models, mis-identified as "the major" IAMs and the "most comprehensive and reliable," are in fact among the simplest of all IAMs in current use.

Simplicity is not necessarily a drawback; it allows for greater transparency in modeling methods, and lowers the cost of performing multiple simulations and analyses with a model. All three models, particularly DICE, have been widely used by other investigators, precisely because of their simplicity and transparency. This is not, however, the same as being exceptionally comprehensive and reliable.

1.d. The default data sets for FUND, PAGE, and DICE are not the only data that should be considered.

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[6] Elizabeth A. Stanton, Frank Ackerman, and Sivan Kartha, "Inside the integrated assessment models: Four issues in climate economics," *Climate and Development* (2009), 1: 166-184.

The transparency of simple models allows a relatively clear view of the data and relationships that drive the model results. For IAMs in general, including FUND, PAGE, and DICE in particular, the software and model relationships are often less decisive than the data inputs in shaping the results. Extensive experiments with DICE by a range of researchers have shown that with small, reasonable changes to the basic data, DICE can yield very different projections (my own contribution to that "modified DICE" literature is cited below). The procedure suggested in the proposed rulemaking not only endorses three specific models; it implicitly endorses the data sets offered by the model's authors. Those data sets embody a number of controversial judgments, which I recommend rejecting as a basis for US policy.

FUND, originally developed by Richard Tol, is now jointly developed by Richard Anthoff and Tol. Its data draws on numerous studies of particular climate-related costs and impacts by Tol and his coauthors. In the analysis of human health and mortality, Tol adopts two troubling conclusions; one is ethically disturbing, and the other is empirically mistaken. First, in the problematical area of monetary valuation of the loss of human life, Tol argues that the value of life in a country depends on how rich it is: as he and two co-authors wrote in a paper on valuation of health, "Following Tol (2002a), we value a premature death at 200 times per capita income."[7] The assumption that higher-income lives are of greater monetary value than lower-income ones is morally offensive; use of this assumption in data and models that form the basis for any US policy is potentially quite embarrassing. I recommend avoiding any trace of that assumption, which would require a complete reworking of Tol's data on health impacts.

Second, Tol and his coauthors conclude, based on a series of mistakes and miscalculations, that the early stages of global warming will cause a huge *reduction* in mortality: an increase of 1°C in the global mean temperature would allegedly save more than 800,000 lives a year by 2050.[8] Valuing these allegedly saved lives at 200 times their per capita incomes creates a huge, spurious benefit of moderate warming, thereby reducing the net cost of climate damages and the SCC. The multiple mistakes in Tol's calculation are explained in a comment I coauthored in the same journal.[9] This is another, separate reason to reject Tol's health impacts data.

Chris Hope, the developer of PAGE, seems to view his dataset, appropriately, as a work in progress. He has responded to several objections to particular data inputs by converting them to uncertain parameters, allowing them to vary in a Monte Carlo analysis. In a recent collaboration between his research group and mine, we came to question the surprisingly low values assumed in PAGE for climate damages to the United States. In an article I coauthored with Hope and two other colleagues, we explored the basis for these low damage estimates.[10] The PAGE dataset assumes that developed countries can and do engage in nearly costless adaptation to most climate

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[7] Francesco Bosello, Roberto Roson, and Richard Tol, "Economy-wide estimates of the implications of climate change: Human health," *Ecological Economics* (2006), 58: 579-591; quote from 585.
[8] Bosello, Roson, and Tol 2006; see Table 1, page 582, for projected changes in the number of deaths.
[9] Frank Ackerman and Elizabeth A. Stanton, "A comment on 'Economy-wide estimates of the implications of climate change: Human health'," *Ecological Economics* (2006), 66:8-13.
[10] Frank Ackerman, Elizabeth A. Stanton, Chris Hope, and Stephane Alberth, "Did the Stern Review underestimate US and global climate damages?", *Energy Policy* (2009), 37:2717-2721.

damages in the next century; PAGE calculates and reports damages net of this extensive adaptation. In addition, PAGE sets a very high temperature threshold for the onset of catastrophic damages, which seems inconsistent with recent scientific discussion of climate risk. Based on changes to these and other assumptions, we produced several alternate estimates for US and global damages due to climate change, ranging up to 5-6 times the PAGE defaults.

The DICE model, developed by William Nordhaus, is known for its projections that the optimal climate policy is a very gradual one, starting on a small scale and expanding at a leisurely pace; Nordhaus refers to this as the "climate policy ramp." However, the gradualism of the default DICE projections is driven by the DICE estimate of climate damages, which is surprisingly low. One factor holding down the overall damage estimates is the assumed benefit of warmer temperatures. On very thin evidence, Nordhaus assumes that most people in the world would be willing to pay for a warmer climate; he concludes that the optimum temperature is a year-round average of 20°C (68°F) – which is the temperature of Houston or New Orleans, and far above the current global average.[11] In an analysis of this feature, I found that removing the assumed benefit of moderate warming had a very large impact on the results from DICE, shifting the model toward recommending much greater urgency about immediate mitigation measures.[12]

Other questions have been raised about the DICE damage figures, such as over-reliance on estimates of agricultural impacts developed in the 1990s; these early estimates were excessively optimistic about potential benefits from warming, and contained some basic analytical errors.[13] In work in progress, UC-Berkeley economist Michael Hanemann has used up-to-date information to re-estimate each of the economic impacts of climate change included in the DICE damage function, concluding that damages in the US could be four times as large as the estimates implied by the DICE defaults.[14]

To summarize this section, the choice of a model, or group of models, should be separated from the endorsement of the default data sets accompanying the models. FUND, PAGE, and DICE can all tell a wide variety of stories and yield a wide range of SCC estimates, depending on the choice of input data. The software is not decisive; the choices about input data made by the models' developers are much more important. These choices, as they stand today, need to be carefully re-examined before they are ready for use as a basis for public policy. FUND, PAGE, and DICE all make unsupported assumptions about input data, which have the effect of lowering estimates of climate damages and the SCC. Alternative estimates imply that damages could be four to six times as large as these models' default datasets assume.

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[11] William Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (MIT Press, 2000), 84-85. The assumed positive value of warmer temperatures for most of the world is still visible in the relatively terse and cryptic "lab notes" documenting the dataset for the newest version of DICE, http://nordhaus.econ.yale.edu/Accom_Notes_100507.pdf (page 24, "time use" column)

[12] Frank Ackerman and Ian Finlayson, "The economics of inaction on climate change: a sensitivity analysis," *Climate Policy* (2006), 6: 509-526.

[13] On errors in an influential early analysis of agriculture and climate change coauthored by Nordhaus, see Schlenker, W., W. M. Hanemann and A. C. Fisher. "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach," *American Economic Review* (March 2005) 395-406.

[14] Michael Hanemann, "What is the Economic Cost of Climate Change?", UC-Berkeley, 2009.

2. Casual, undocumented estimates are used to justify the proposed choice of discount rates

The discussion of discount rates (Federal Register pages 49613-49616) offers a collection of arguments leading to a recommendation of two alternate discount rates, 3% and 5%. Although the opening of this section notes correctly that "decisions based on cost-benefit analysis with high discount rates might harm future generations" (49613), casual estimates and unsupported judgments are used to justify discount rates that are inappropriately high for intergenerational analysis.

The Office of Management and Budget (OMB) guidelines encourage sensitivity analysis with discount rates below 3% for intergenerational problems ("If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower [than 3%] but positive discount rate…", OMB as quoted on 49613). EPA and NHTSA have not presented such an analysis; no explanation is offered for ignoring this portion of OMB guidance.

Beyond the introductory and framing remarks, there are three substantive sections to the discussion of discount rates:

    a. Discount rates can be based on current market interest rates
    b. Discount rates can be derived from the "Ramsey equation" of economic theory
    c. There are reasons to consider declining, rather than constant, discount rates

The discussion of the first two points offers very casual derivations of excessively high discount rates. On the third point, the proposed rulemaking declines to make a judgment.

2.a. The proposed rulemaking exaggerates and misuses current market interest rates

As noted in the proposed rulemaking, discount rates are at times based on market interest rates. The proposal goes on to state without documentation that

> …3% is close to the risk-free rate of return, proxied by the return on long term inflation-adjusted U.S. Treasury Bonds… Although these rates are currently closer to 2.5%, the use of 3% provides an adjustment for the liquidity premium that is reflected in these bonds' returns. (49614)

This is inappropriate because there is no clear argument for adding a liquidity preference adjustment to observed interest rates – and because the risk-free rate of return is almost never as high as 2.5%. I have downloaded and examined two data series for inflation-adjusted long-term rates; both are from the Department of the Treasury's Office of Debt Management. One is for 10-year Treasury Inflation Protected Securities (TIPS); the other is for the Treasury's Real Long-term Rate Average index, described on the Treasury website as "intended as a proxy for long-term real rates." Both series are available on a daily basis beginning in January 2003. (The rate on 20-year TIPS, available since mid-2004, is very close to the Real Long-term Rate Average.)

The data for these two series are shown in Figure 1, below. Summary statistics are presented in Table 1. As my calculations demonstrate, neither of these two series spends much time above 2.5%. Plausible versions of the recent average rate of return in these data series range from 1.7% to 2.3%. So if the discount rate is based on these data, 2% would be a better estimate than 3%.

Table 1: Real rates of return on U.S. Treasury bonds, January 2003 – October 2009		
	10-year TIPS	Real Long-Term Rate Average
Number of daily observations	1,711	1,711
Number of days above 2.5%	105 (6.1%)	292 (17.1%)
Average, January 2003 – October 2009	1.98%	2.26%
Average, January 2009 – October 2009	1.72%	2.30%
Source: calculated from data downloaded from http://www.treas.gov/offices/domestic-finance/debt-management/interest-rate/ .		

Even 2% is higher than estimates of the (inflation-adjusted) risk-free rate of return commonly found in the economics literature; many authors suggest rates of 1% or less. Richard Howarth, a Dartmouth University economist who has analyzed the relationship between discount rates and long-run rates of return, notes that investors in U.S. Treasury bills averaged an inflation-adjusted return of 0.7% pre-tax or 0.0% after-tax for most of the twentieth century. Corporate bonds, with low but not zero risk, averaged 2.6% real return pre-tax or 1.5% after-tax over the same period.[15] A discount rate based on long-run average returns, in other words, might suggest even lower rates than the averages presented in Table 1.

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[15] Richard Howarth, "Discounting and Uncertainty in Climate Change Policy Analysis," *Land Economics* (2003) 79: 369-381.

Figure 1: Real interest rates on U.S. Treasury bonds, 2003 - 2009

Long-term real rate

10 year TIPS
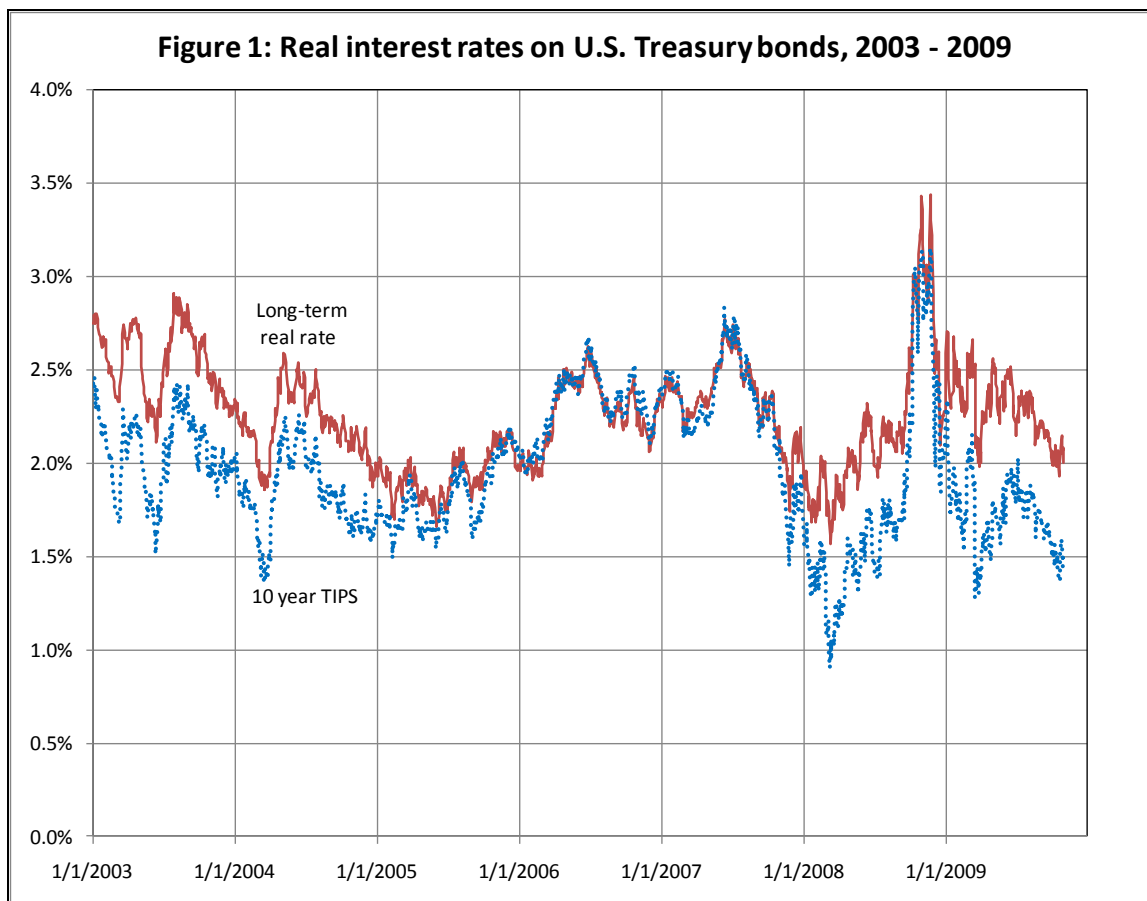
The proposed rulemaking goes on to suggest that alternatively, a 5% discount rate could be based on the observed return on risky investments, as measured by the S&P 500 stock index. This is mistaken both in fact and in theory. Empirically, the average real rate of return on stocks is clearly higher than 5%. From 1988 through 2008, the nominal rate of return on the S&P 500 averaged 10.7% per year.[16] Since inflation averaged just over 3% in those years, the average real rate of return on the S&P 500 was greater than 7%.

This does not matter for the choice of a discount rate, however, since it is not appropriate to use the rate of return on risky assets. As is widely recognized,[17] the rate of return on risky assets should only be used to discount costs and benefits when the expected returns are correlated with the broader economy. This does not apply to greenhouse gas mitigation: the returns to investment in mitigation will be greatest when potential climate damages would have the worst effects on the economy; thus the returns to mitigation are countercyclical. Mitigation should be interpreted as a form of insurance against climate damages, a topic addressed in the last section of my comments, below; the returns to insurance are always greatest when losses occur, i.e. when returns on other assets are low. The same conclusion – it is inappropriate to base discount

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[16] Calculated from data downloaded from http://www2.standardandpoors.com/spf/xls/index/MONTHLY.xls .
[17] See, among many others, Howarth 2003, and Federal Register 49614, footnote 369.

rates on market rates of return on risky assets – therefore applies to any insurance-like policies and measures, in climate policy or other arenas.

2.b. The proposed rulemaking misuses the Ramsey equation to support its preferred discount rates

As an alternative to using market rates of return to set discount rates, economists have often used a theoretical framework built on the work of Frank Ramsey, an early twentieth-century economist. Under a number of strong simplifying assumptions, including the assumption of certainty about the future growth of incomes, this framework reduces to a now-familiar equation: the optimal discount rate is the sum of the rate of pure time preference, plus a multiple of the rate of growth of per capita consumption. It is often forgotten that, when the future is uncertain, there is a third, negative component to the Ramsey equation, proportional to the variance in future growth rates. That is, the more uncertain the future is, the lower the appropriate discount rate.[18]

The proposed rulemaking offers arbitrary, unsupported judgments about the first two components of the Ramsey equation, and ignores the third component which calls for a lower discount rate under conditions of uncertainty.

Specifically, the proposed rulemaking asserts that "a common estimate" of the pure rate of time preference is 2%, and that "standard estimates… from the economics literature" of the term involving per capita consumption are 3% - 5% (quotes from Federal Register 49614). This would appear to imply a discount rate of 5% to 7%, in the absence of the uncertainty term. There are, however, no such things as "standard estimates" of these controversial quantities. Five sources are cited in support of these supposedly standard estimates; four of them do not agree with the numerical estimates discussed in the proposed rulemaking. A summary of the evidence in the cited articles is provided in Table 2.

Of the five cited sources, Nordhaus is the outlier, endorsing a roughly 5% discount rate, but even he projects a significantly lower rate for the long run. Dasgupta might recommend a 5% discount rate with fast enough economic growth; he, however, emphasizes the failure of this framework under plausible levels of uncertainty.

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[18] For more explanation, including discussion of the simplifying assumptions behind the Ramsey equation and citations to sources in the finance literature, see Frank Ackerman, Stephen DeCanio, Richard Howarth, and Kristen Sheeran, "Limitations of integrated assessment models of climate change," *Climatic Change* (2009) 95:297-315.

Table 2: Discount rates based on the Ramsey equation			
Source	Pure time preference	Per capita consumption term	Discount rate and comments
Arrow et al. 1996			Many values discussed, no recommended value; numerical examples most often assume Ramsey discount rate = 2%
Dasgupta 2008	Supports ethical grounds for zero	Often, 2 times growth rate	Discusses limits of simple Ramsey framework, its failure under uncertainty
Hoel and Sterner 2008	No recommendation; often uses 0.1%	Often uses 1.5 times growth rate	Discusses need to modify Ramsey framework, suggests a range of rates from -1.6% to +2.9%
Nordhaus 2008	1.5%	2 times growth rate	5.5% for first 50 years, lower later
Stern 2008	0.1%	1 times growth rate	1.4% on most likely scenario
EPA/NHTSA, based on above	**2%**	**3%-5%**	**5%**
Source: My reading of the five references cited in Federal Register 49614, footnote 370.			

If the Hoel and Sterner recommendation is taken as the midpoint of their suggested range, then three of the five sources cited in support of a 5% discount rate actually endorse, or lean toward, 2% or less. None of the cited sources endorse pure time preference as high as the EPA/NHTSA guess of 2%. In short, the casual derivation of a discount rate from the Ramsey equation on page 49614 of the proposed rulemaking does not appear to be based on a careful reading of the sources cited in its supporting footnotes.

Moreover, as some of the cited sources recognize, there is a need to modify the framework to account for uncertainty; that modification leads to a reduction in the Ramsey equation estimate of the discount rate.

For a detailed literature review on the issues of discounting, including the ethical arguments for a near-zero rate of time preference, I recommend Chapter 2 of the Stern Review and its appendices. They provide extensive citations to the peer-reviewed literature on the subject.

2.c. The proposed rulemaking raises but fails to make a decision about the arguments for a declining discount rate

While a constant discount rate is often taken for granted, there are many reasons to consider a discount rate that declines over time. The proposed rulemaking cites two key analyses that propose reasons for declining discount rates, by Newell and Pizer and by Weitzman,[19] but then describes these as "relatively recent" contributions to the economic literature (Federal Register, 49615, main text and footnote 378) and invites comments on them. This description is hard to

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[19] Richard Newell and William Pizer, "Discounting the distant future: how much do uncertain rates increase valuations?", *Journal of Environmental Economics and Management* (2003), 46:52-71; Martin Weitzman, "Why the far-distant future should be discounted at its lowest possible rate," *Journal of Environmental Economics and Management* (1998), 36:201-208.

understand: Newell and Pizer's paper was published in a journal in 2003, but widely circulated two years before that; Weitzman's analysis, cited as a 2001 publication, actually appeared in a journal in 1998. A major literature review, which appeared in the AEA's *Journal of Economic Literature* in 2002, discussed numerous arguments for time-varying discount rates.[20] As that review explains, the notion of a constant discount rate was first introduced in a short paper by Paul Samuelson in 1937, which presented the constant rate as a simple approximation to a complex reality. Many authors before and since Samuelson have explored other approaches to time discounting.

Newell and Pizer demonstrate that if discount rates are based on interest rates, and interest rates will experience unpredictable variation in the future, then the effective discount rate applied to future outcomes is reduced as time passes. In their terminology, the "certainty-equivalent [discount] rate" falls continuously over time. Weitzman reaches the same conclusion from a theoretical analysis based on a different formal model of uncertainty, which suggests the robustness of this conclusion.

The arguments for constant discount rates, aside from mathematical simplicity, are that a declining rate creates opportunities for arbitrage, or leads to time-inconsistent policy advice. No one, however, has the life span or resources to arbitrage against multi-century public policies. And an analysis of the question of time-inconsistent advice has shown that there is minimal risk of this problem arising from declining discount rates.[21] Thus it is time to embrace the no-longer-recent innovation of declining discount rates for climate policy analysis.

3. The fundamental issue of catastrophic climate risk is only mentioned in passing

Following the body of the analysis, the proposed rulemaking presents four final caveats (49616-49617). The third of these points is the question of accounting for catastrophic risk and worst-case scenarios, as raised in the economics literature by Martin Weitzman.[22] In this case, the work in question is relatively recent, as stated in the proposed rulemaking: Weitzman's major paper on the subject was published in early 2009, although he had anticipated its result in a 2007 paper; both circulated widely before publication. In addition, Weitzman's analysis is conducted at a level of mathematical abstraction that deters many readers. The proposed rulemaking asks for comments on Weitzman's analysis.

Despite its difficult presentation, Weitzman's result is of fundamental importance. The "dismal theorem" of his 2009 paper demonstrates that, in cases of limited information about potentially

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[20] Shane Frederick, George Loewenstein, and Ted O'Donoghue, "Time discounting and time preference: A critical review," *Journal of Economic Literature* (2002) 40:351-401.
[21] Anders Hansen, "Do declining discount rates lead to time inconsistent economic advice?", *Ecological Economics* (2006) 60:138-144.
[22] Martin Weitzman, "On Modeling and Interpreting the Economics of Catastrophic Climate Change," *Review of Economics and Statistics* (2009), 91:1-19; see also Weitzman, "A Review of the Stern Review on the Economics of Climate Change," *Journal of Economic Literature* (2007), 45:703-724.

unbounded risks, the expected value of risk reduction can be infinite. He argues persuasively that the catastrophic risks explored by climate scientists involve worst-case losses that are effectively unbounded, and that the climate system is so complex and dynamic that our information about it is necessarily limited. In my own recent writing I have provided a more extended, completely non-technical presentation of the Weitzman analysis of uncertainty as applied to climate change.[23] As Nicholas Stern (2008) has noted, Weitzman's work can be seen as presenting the mathematical foundation for the precautionary principle.

In non-technical terms, the Weitzman result suggests that policy should be directed at reducing the risks of worst-case outcomes, not at balancing the most likely values of costs and benefits. This fits well with a large portion of the prevailing discourse on climate change. The expected damages from climate change are important and costly; the credible worst-case outcomes are disastrously greater. The urgent priority is to protect ourselves against those worst cases, not to fine-tune expenditures to the more modest, most likely level of damages.

Protection against worst case scenarios is familiar, though it takes us outside the realm of cost-benefit analysis, into the discussion of insurance policies. Insurance is normally taken out against events which, on average, are unlikely to occur: the average U.S. housing unit can expect to have a fire every 250 years, so the most likely number of residential fires you will experience in your lifetime is zero.[24] Moreover, insurance is guaranteed to fail a simple cost-benefit test – the average value of payments to policyholders must be less than the average value of premiums, in order for the insurance company to remain in business.

Policy designed from this perspective would not be framed in terms of cost-benefit calculations. Rather, it would begin with adoption of a safe minimum standard, based on the scientific analysis of potential risks. The economic analysis would then seek to determine the least-cost strategy for meeting that standard. For example, in a recent analysis, I and a group of coauthors examined the costs of meeting the 350 ppm target for atmospheric CO_2 concentration, which is now advocated by a growing number of climate scientists and policy analysts.[25] The best available estimates suggest that the costs will be noticeable, but far less damaging than the costs of failing to meet that target.

And strict tailpipe emission standards for U.S. cars and trucks will undoubtedly be on the least-cost path to a safe climate standard such as 350 ppm.

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[23] Frank Ackerman, *Can We Afford the Future? Economics for a Warming World* (2009), Zed Books, chapter 3.
[24] See Ackerman 2009, chapter 3, for details.
[25] Frank Ackerman, Elizabeth A. Stanton, Stephen DeCanio, Eban Goodstein, Richard Howarth, Richard Norgaard, Catherine Norman, and Kristen Sheeran, "The Economics of 350: The Benefits and Costs of Climate Stabilization," October 2009, http://www.e3network.org/papers/Economics_of_350.pdf .