

Tol, Richard S. J.

Article

The Social Cost of Carbon: Trends, Outliers and Catastrophes

Economics: The Open-Access, Open-Assessment E-Journal

Provided in Cooperation with:

Kiel Institute for the World Economy – Leibniz Center for Research on Global Economic Challenges

Suggested Citation: Tol, Richard S. J. (2008) : The Social Cost of Carbon: Trends, Outliers and Catastrophes, Economics: The Open-Access, Open-Assessment E-Journal, ISSN 1864-6042, Kiel Institute for the World Economy (IfW), Kiel, Vol. 2, Iss. 2008-25, pp. 1-22,
<https://doi.org/10.5018/economics-ejournal.ja.2008-25>

This Version is available at:

<https://hdl.handle.net/10419/18038>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<http://creativecommons.org/licenses/by-nc/2.0/de/deed.en>

The Social Cost of Carbon: Trends, Outliers and Catastrophes

Richard S.J. Tol

Economic and Social Research Institute, Dublin, Ireland; Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands; Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands; Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

Abstract:

211 estimates of the social cost of carbon are included in a meta-analysis. The results confirm that a lower discount rate implies a higher estimate; and that higher estimates are found in the gray literature. It is also found that there is a downward trend in the economic impact estimates of the climate; that the Stern Review's estimates of the social cost of carbon is an outlier; and that the right tail of the distribution is fat. There is a fair chance that the annual climate liability exceeds the annual income of many people.

JEL: Q54

Keywords: Climate change; social cost of carbon

Correspondence: Richard S.J.Tol, ESRI, Whitaker Square, Sir John Rogerson's Quay, Dublin 2, Ireland, richard.tol@esri.ie.

Comments by Cameron Hepburn, Steve Rose, Gary Yohe, and two anonymous referees helped to improve the paper. Funding by the ESRI's Energy Policy Research Centre is gratefully acknowledged.

1 Introduction

Estimates of the social cost of carbon (dioxide emissions), or the marginal damage cost of climate change are an essential ingredient to any assessment of climate policy. The social cost of carbon (SCC) is a first estimate of the Pigou tax that should be placed on carbon dioxide emissions. Indeed, if the SCC is computed along a trajectory in which the marginal costs of emission reduction equal the SCC, the SCC is the Pigou tax. Few would argue that climate policy should be set by cost-benefit analysis alone, but most economists would feel uneasy if climate policy would drift too far from its optimum—although analysts in other disciplines are less compelled by the branch of utilitarianism that is common in economics. This paper presents a meta-analysis of over 200 estimates of the SCC, and tests three hypotheses:

- The Stern Review is an outlier in the literature (Tol 2006).
- The economic estimates of the impact of climate change increase over time (Schneider et al. 2007).
- The uncertainty about the social cost of carbon has a fat right tail (Weitzman 2007b).

In Tol (2005), I also presented a meta-analysis of the SCC. There are four reasons for the current update. Firstly, the number of estimates has roughly doubled. Tol (2005) was part of a larger study that led to many new estimates, but other studies were published as well—and my attention was drawn to a handful of estimates I had previously overlooked. See Table A1 for the full list of estimates.¹ Secondly, the Stern Review (Stern et al. 2006) was published, provoking renewed interest in cost-benefit analyses of climate policy (Anderson 2007; Byatt et al. 2006; Carter et al. 2006; Dasgupta 2007; Dietz et al. 2007a, b; Hamid et al. 2007; Mendelsohn 2006; Nordhaus 2007a, b; Spash 2007; Stern and Taylor 2007; Tol 2006; Tol and Yohe 2006, 2007a; Yohe 2006; Yohe and Tol 2006; Yohe et al. 2007; note that these are the published papers only—various journals are preparing special issues). The Stern Review also published an estimate of the SCC. Although many newspapers publicised the Stern Review as entirely novel, its estimate is in fact number 211 in chronological order. A number of people argued that the Stern Review is an outlier. This paper formally tests this assertion. Thirdly, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) was published (Schneider et al. 2007). It argues that economic estimates of the impact of climate change have become more pessimistic since the previous report of 2001. This paper formally tests this assertion as well. Fourthly, Weitzman (2007b) argues that climate economics has unduly focussed on the middle of the probability distribution, and should have focussed on the tails. This paper supports that argument. Fourthly, I estimate the risk premium and the fraction of people that would be able to afford the estimated carbon tax.

Although there are now over 200 estimates of the SCC, research in this area is still less developed than one would wish. The 200 estimates of the *marginal* costs of climate change are based on a dozen of estimates of the *total* costs of climate change (Cline 1992; Fankhauser 1995; Maddison 2003; Mendelsohn et al. 2000; Nordhaus 1991,

¹ Note that most studies do not specify the year for which the estimate is valid. As rough indication, one can work with the assumption that the social cost of carbon is expressed in US dollars of around 1995, and hold for emissions around the year 2000.

1994, 2006; Nordhaus and Boyer 2000; Nordhaus and Yang 1996; Rehdanz and Maddison 2005; Tol 1995, 2002).² The total cost estimates omit some impacts of climate change; they tend to ignore interactions between different impacts, and neglect higher order effects on the economy and population; they rely on extrapolation from a few detailed case studies; they often impose a changing climate on a static society; they use simplistic models of adaptation to climate change; they often ignore uncertainties; and they use controversial valuation methods and benefit transfers.

Unfortunately, this list of caveats³ has not changed much since Fankhauser and Tol (1996). The proximate reason is that few people work in this area, and none full time, as funding is difficult to get. The ultimate reasons are, firstly, that the issues are complex and uncertain, and require broad multidisciplinary knowledge and, secondly, that the results are unpopular with climate policy makers.

However, climate change is climbing the international policy agenda again—and certain countries do require a cost-benefit analysis on any major policy decision. Some countries prefer to cook the books rather than do serious analysis (e.g., Clarkson and Deyes 2002; Pearce 2003; CEC 2005a, b; Tol 2007), but other countries try to use the best available knowledge. In this paper, I present that—but the reader should be aware that “best available” does not mean “good” in this case.

In Section 2, I present the data and methods. Section 3 shows the results for the monetary estimates, while Section 4 estimates the risk premium and distributional implications. Section 5 concludes.

2 Data and Methods

211 estimates of the SCC were gathered from 47 studies.⁴ See Table A1. The estimates are for different years, but most roughly represent the marginal damage costs for emissions in the year 1995, discounted to 1995, and measured in 1995 US dollars. The studies were grouped in those that were peer-reviewed and those that were not (PR in Table A1). Note that some of the more recent studies are currently under peer-review, but they are counted as gray literature until published. Some studies are based on original estimates of the total costs of climate change, while other studies borrow total costs estimates from other studies (IE in Table A1). Most studies use incremental or marginal calculus to estimate the SCC, as they should, while a few others use average impacts or an unspecified method (ME in Table 1). Some studies assume that climate changes but society does not (i.e., all income elasticities are zero), while other studies include a dynamic model of vulnerability (DM in Table A1). A few studies use entirely

² Note that Nordhaus and Mendelsohn are colleagues; that Fankhauser, Maddison and Tol worked with David Pearce and each other in the formative stages of their careers; and that Rehdanz used to be a PhD student of Maddison and Tol.

³ Some people would argue that climate change is not a marginal change, and that therefore the marginal damage costs of carbon dioxide emissions are an inappropriate measure. This reasoning is incorrect, as any emission reduction has a only a small effect on climate change. The social cost of carbon should be used to inform emission reduction.

⁴ Most of the estimates of the SCC are along a business as usual scenario of greenhouse gas emissions, but some are along a path of optimal control. Two estimates of the SCC by Stern et al. (2006) were omitted because they are along a path of arbitrary emission reduction.

Table 1: Selected Characteristics^a of the Joint Probability Density of the Social Cost of Carbon for the Whole Sample (all) and Selected Subsamples^b

	All	PRTP			Review		Publication date		
		0%	1%	3%	peer	gray	<1996	1996–2001	>2001
<i>Fisher-Tippett, sample standard deviation</i>									
Mode	35	129	56	14	20	53	36	37	27
Mean	127	317	80	24	71	196	190	120	88
St.Dev.	243	301	70	21	98	345	392	179	121
Median	74	265	72	21	48	106	88	75	62
90%	267	722	171	51	170	470	397	274	196
95%	453	856	204	61	231	820	1,555	482	263
99%	1,655	1,152	276	82	524	1,771	1,826	867	627
Stern	0.92	0.56	1.00	1.00	0.97	0.84	0.86	0.92	0.96
<i>Gauss, sample standard deviation</i>									
Mode	33	136	46	14	21	46	32	35	29
Mean	88	220	55	16	49	135	131	83	61
St.Dev.	243	298	70	21	98	345	392	178	121
Median	47	194	53	16	33	65	49	50	42
90%	213	626	146	44	142	350	298	221	164
95%	371	747	172	52	201	766	1,453	428	219
99%	1,623	953	221	67	503	1,734	1,782	843	610
Stern	0.94	0.65	1.00	1.00	0.97	0.89	0.91	0.94	0.97
<i>Gauss, sample coefficient of variation</i>									
Mode	0	19	5	2	3	0	4	5	0
Mean	102	225	55	16	55	144	125	100	68
St.Dev.	351	342	69	20	186	437	424	323	223
Median	15	107	34	10	14	18	14	16	17
90%	304	676	151	43	159	407	360	264	210
95%	596	989	195	58	310	891	808	537	361
99%	2,025	1,502	285	89	885	2,420	2,411	1,841	1,127
Stern	0.90	0.76	0.99	1.00	0.95	0.87	0.89	0.92	0.94

^aMode, mean, standard deviation, median, 90-percentile, 95-percentile, 99-percentile, percentile of the Stern estimate. ^bPure rate of time preference, review process, and publication date.

arbitrary assumptions about future climate change, while most studies are based on internally consistent scenarios (SC in Table A1). These classifications are used as quality indicators.⁵ Specifically, the sum of the values in Table A1 is the “quality” of the study. More recent studies receive a higher weight—publication year minus 1980 over 10—so that age contributes up to one-third of the total quality weight. Many of the studies report multiple estimates. Most of the estimates are sensitivity analyses around a central estimate, and some estimates are only included to (approximately) reproduce an earlier study. The quality weight of a study is distributed over the alternative estimates in that study on the basis of my assessment of what the author thinks are more and less

⁵ Note that the five quality indicators are objective. The aggregation is arbitrary.

credible assumptions. Tol (2005) reports a sensitivity analysis, and finds that the results are robust.

The 211 estimates are classified as follows. Most estimates use the Ramsey discount rule— $\delta = \rho + \eta g$ —but some estimates use a constant consumption discount rate rather than a constant utility discount rate. A few recent studies use a *declining* discount rate (inspired by Gollier 2002, and Weitzman 2001), a few studies fail to report what discount rate was used, and a few studies include the discount rate in the uncertainty analysis. Some studies use equity weighting (Fankhauser et al. 1997) with the global average income as normalisation (Anthoff et al., forthcoming), but most studies simply add the regional dollar values (for which normalisation is irrelevant; cf. Fankhauser et al. 1998). The discount rate and the age of the study are used to split the sample.

I adjust three alternative kernel density estimators to these data points. Essentially, a kernel density estimator assigns a probability density function to each data point, and the kernel estimator is the weighted sum of these PDFs. As always, the standard choice is the Gaussian distribution. The 211 estimates provide the modes. Only a few of the studies provide an estimate of the uncertainty. Therefore, either the standard deviation or the coefficient of variation is set equal to the sample standard deviation or the sample coefficient of variation. However, the uncertainty in the sample is right-skewed and fat-tailed. Therefore, the Fisher-Tippett distribution is also used, with the modes equal to the best guesses and the standard deviations equal to the sample standard deviation. The coefficient of variation of the Fisher-Tippett distributed is bounded from above at about 1.7, which is smaller than the sample coefficient variation. However, the Fisher-Tippett distribution is the only distribution that is right-skewed, fat-tailed, and defined on the entire real line.

3 Results

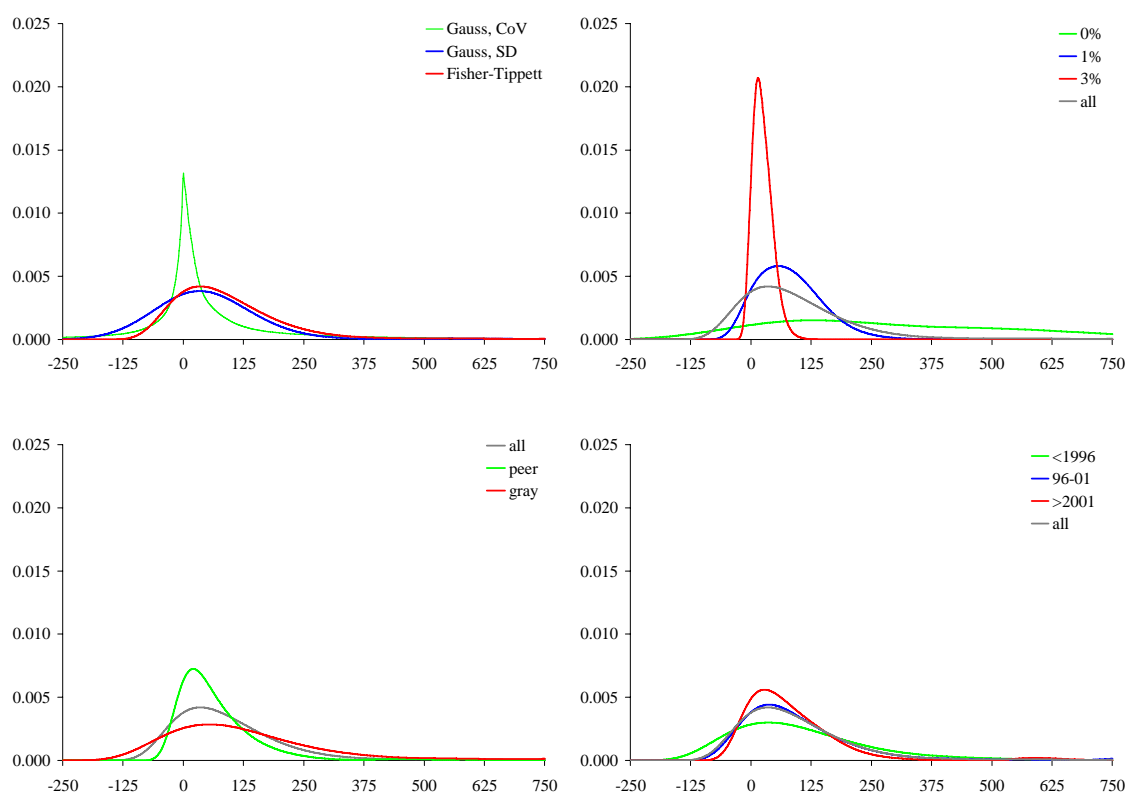
Table 1 shows selected characteristics of the kernel distributions for the whole sample and selected sub-samples. Figure 1 shows the probability density functions.

Unsurprisingly, the Fisher-Tippett kernel has fatter tails and therefore higher means and medians than the Gauss kernel. The modes are about the same. Using the Gauss kernel with the sample coefficient of variation rather than the sample standard deviation has mixed effects. The estimates near zero get higher weight, and this pulls the mode and median down. However, the high estimates are spread thinly over a wide range, and this implies fatter tails and a higher mean.

Splitting the sample by discount rate used has the expected effect: A higher discount rate implies a lower estimate of the SCC and a thinner tail. Table 1 also shows that estimates in the peer reviewed literature are lower and less uncertain than estimates in the gray literature. This confirms the findings of Tol (2005).

Splitting the sample by publication date, shows that the estimates of the SCC published before AR2 (Pearce et al. 1995) were larger than the estimates published between AR2 and AR3 (Smith et al. 2001), which in turn were larger than the estimates published since. Note that these differences are not statistically significant if one considers the means and standard deviation. However, the kernel distribution clearly shifts to the left. Therefore, AR4 (Schneider et al. 2007) were incorrect to conclude that

Figure 1: The Kernel Estimate of the Probability Density Function of the Social Cost of Carbon^a



^aTop left: alternative distributional assumptions; top right: sample split according to pure rate of time preference; bottom left: sample split according to review; bottom right: sample split according to age of study. The Fisher-Tippett distribution is used throughout (except top left).

the economic estimates of the impact of climate change have *increased* since 2001. In their words (p. 781): “There is some evidence that initial new market benefits from climate change will peak at a lower magnitude and sooner than was assumed for the TAR, and it is likely that there will be higher damages for larger magnitudes of global mean temperature increases than was estimated in the TAR.” It is unclear how Schneider et al. (2007) reached this conclusion, but it is not supported by the data presented here. Then again, impacts of the economic impacts of climate change necessarily lag behind the latest insights from natural scientists, which indeed justify some increase in the alarm about climate change. Perhaps Schneider et al. (2007) speculate on the results of future research in economics, a clear violation of the IPCC mandate.

Tol (2005) also finds a downward trend in the estimates of the social cost of carbon. However, the mean estimates of the SCC are higher in this paper than in Tol (2005). This is due to the different treatment of uncertainty. The Gauss/Coefficient of Variation estimates in this paper are methodologically closest to the method used in Tol (2005), and the results are similar. The Gauss/Standard Deviation and particularly the Fisher-Tippett/Standard Deviation estimates put more emphasis on the uncertainty, which leads to higher numbers.

Table 2 splits the sample by author. Three authors have contributed a range of papers on the social cost of carbon: Chris Hope, William Nordhaus, and Richard Tol. Separate results are shown for these three and for all other authors. Table 2 reveals no significant differences—the uncertainties are simply too large—but Nordhaus' estimates are lowest, followed by Hope, Tol, and other authors. It is noteworthy that repeat contributors to the literature on the social cost of carbon are less pessimistic about the impact of climate change.

The SCC estimate by Stern et al. (2006) is almost an outlier in the entire sample (excluding, of course, the Stern estimate itself). Depending on the kernel density, the Stern estimate lies between the 90th and the 94th percentile. Compared to the peer-reviewed literature, the Stern estimate lies beyond the 95th percentile—that is, it is an outlier. The Stern estimate fits in better with estimates that use a low discount rate and were not peer-reviewed—characteristics of the Stern Review—but even in comparison to those studies, Stern et al. (2006) are on the high side. Interestingly, the estimate by Stern et al. (2006) is based on Hope's PAGE model but is an outlier compared to earlier estimates with that model (see Table 2). The Stern estimate also fits in better with the

Table 2: Selected Characteristics^a of the Joint Probability Density of the Social Cost of Carbon for the Whole Sample (all) and Author-Based Subsamples^b

	All (211)	Hope (48)	Nordhaus (8)	Tol (112)	Other (53)
<i>Fisher-Tippett, sample standard deviation</i>					
Mode	35	22	8	34	64
Mean	127	42	28	68	207
St.Dev.	243	60	42	86	337
Median	74	31	17	53	120
90%	267	84	65	157	511
95%	453	113	145	205	797
99%	1,655	435	176	394	1,762
<i>Gauss, sample standard deviation</i>					
Mode	33	20	8	29	55
Mean	88	29	19	47	143
St.Dev.	243	60	42	86	337
Median	47	22	11	37	77
90%	213	68	49	130	395
95%	371	88	138	174	730
99%	1,623	423	168	366	1,723
<i>Gauss, sample coefficient of variation</i>					
Mode	0	4	6	0	1
Mean	102	32	20	49	156
St.Dev.	351	119	86	137	438
Median	15	15	7	12	27
90%	304	82	43	161	455
95%	596	116	103	247	952
99%	2,025	440	459	593	2,378

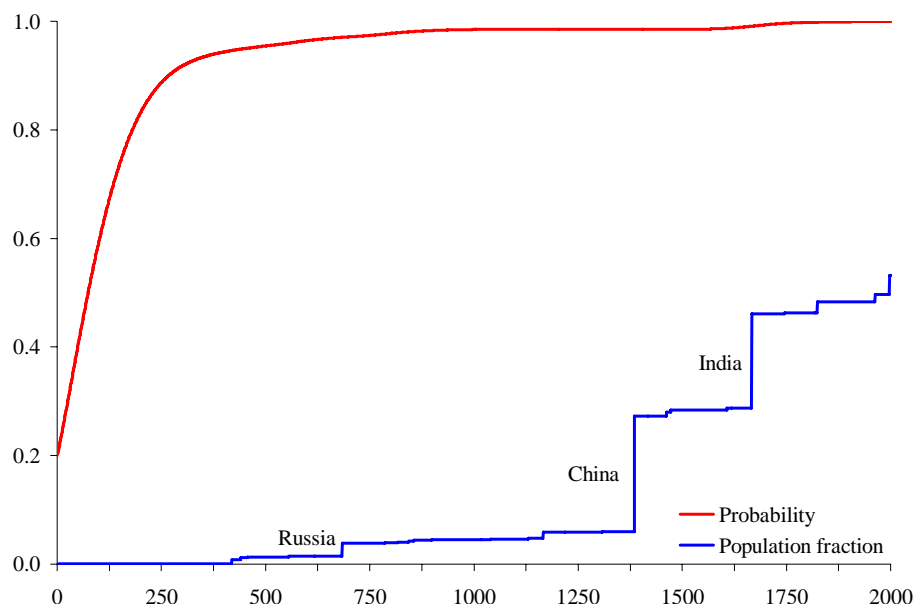
^aMode, mean, standard deviation, median, 90-percentile, 95-percentile, 99-percentile. ^bThe numbers in brackets are the number of estimates.

older studies. This is no surprise, as the PAGE model (e.g., Hope 2006) is updated only with great delay—that is, after the literature reviews by the IPCC (Pearce et al. 2005; Smith et al. 2001). It does fly in the face, though, of the assertion by Stern et al. (2006) to have used the latest research. Even though the Stern et al. (2006) estimate is almost an outlier, this of course does not mean that it is wrong. However, the most positive verdict in the economic literature on the Stern Review is that it was right for the wrong reasons (Arrow 2007; Weitzman 2007a).

4 Catastrophic Liability

Weitzman (2007b) argues that the uncertainty about climate change may be so profound that the expected welfare loss is unbounded. See also Tol (2003) and Tol and Yohe (2007b). Figure 2 has a different take on this. It plots the cumulative kernel density estimate (Fisher-Tippett), and the fraction of the world population for whom the “liability of climate change” (i.e., the SCC times their emissions) exceeds their per capita income. See Tol and Verheyen (2004) for a discussion on liability and impacts of climate change. Figure 2 is based on three rather strong assumptions. Firstly, it assumes that people are liable for their greenhouse gas emissions and compensate the victims. Secondly, Figure 2 only considers the compensation paid but disregards the compensation received. Thirdly, it assumes that liability for emissions does not induce

Figure 2: The Cumulative Kernel Density Function of the Social Cost of Carbon (in \$/tC) and the Fraction of the World Population for Whom the Total “Carbon Tax” Exceeds Income^a



^aPopulation, per capita income, and per capita CO₂ emissions are for year 2002 from <http://earthtrends.wri.org>.

greenhouse gas emission reduction. Although clearly unrealistic, Figure 2 does provide insight into the scale of the climate problem.

For a rising SCC, first the countries with high emission intensity (CO₂ emissions per gross domestic product) would be “bankrupted”—that is, the annual carbon liability (if paid without reducing emissions) would exceed the annual income for the average person. Using 2002 data, the Ukraine would be the first country to which this would happen.⁶ A carbon liability of \$418/tC would be too much.⁷ The probability that the SCC exceeds \$418/tC varies between 5% and 7%. See Table 3. This is a high probability for an “infinite” loss—but such a high liability would trigger emission reduction, other countries may come to the assistance of the Ukraine, and it is unlikely to impose such a high tax in the first place.

Table 3 also shows the SCCs that would “bankrupt” 1%, 5%, and 10% of the world population, and the associated probabilities. Obviously, the SCCs are higher, and the probabilities smaller—but there is still a probability of 1–2% that the SCC is larger than \$1385/tC, which would “bankrupt” more than 10% of the world population. For all three kernel distributions, there is a positive probability that more than 60% of the world population is “bankrupted”. The expected fraction of the world population that goes “bankrupt” lies between 0.6% and 1.1%.

A comparison of Table 3 and Table 1 reveals the probability of “bankruptcy” is dominated by the discount rate, the gray literature, and older studies. Newer studies published in peer-reviewed journals based on high discount rates estimate only a very small chance of a carbon liability in excess of annual income.

Finally, Table 3 shows the risk premium of the SCC for the average person on Earth. The risk premia vary between 15% and 27%—for the average. For over 60% of the world population, the risk premium is infinite. This confirms Weitzman’s (2007b) claim that climate policy analysis is dominated by the tails of the distribution. It also highlights that climate is an equity problem.

The results in Figure 2 and Table 3 omit emission reduction, but a simple scaling of the results gives a crude estimate of the effect of emission reduction. According to Table 3, a carbon liability of \$440/tC would equal 100% of income for 1% of the world population. If a liability of \$880/tC would reduce emissions by 50%, then \$880/tC would equal 100% of income for 1% of the world population. However, in the short-term, emission reductions will be far less than 50%.

The results change when we recast the numbers as a “carbon tax” rather than a “carbon liability”. The price of carbon is the same, but the revenue flows to the government and is presumably recycled as lower taxes and higher benefits. A carbon tax of \$440/tC (or \$880/tC with a 50% emission reduction) would imply that 1% of the world population would pay 100% of its income in carbon taxes, and would live of government benefits.

⁶ Note that although richer people within a country tend to emit more greenhouse gases than do poorer people, but that the emissions distribution typically is less skewed than the income distribution. This implies that the poor in the Ukraine would be hit harder by a carbon liability than would the rich.

⁷ Note that a country like the Ukraine is not particularly vulnerable to climate change, and would therefore receive less compensation than it would pay.

Table 3: The Social Cost of Carbon for Which 1% / 5% / 10% of the World Population Would Be “Bankrupted by a Carbon Tax”, and their Exceedance Probability According to Three Alternative Kernel Densities^{ab}

	SCC	Probability		
	\$/tC	FT	G (SD)	G (Cov)
1 st	418	5.4%	4.7%	7.3%
1%	440	5.1%	4.5%	6.9%
5%	1,166	1.5%	1.4%	2.4%
10%	1,385	1.4%	1.4%	2.0%
Exp.		0.7%	0.6%	1.1%
RP		15%	18%	27%

^aFisher-Tippett with sample standard deviation; Gauss with sample standard deviation; Gauss with sample coefficient of variation. ^bAlso shown are the SCC that triggers the first bankruptcy and its exceedance probabilities; the expected fraction of the population that faces “bankruptcy” (exp); and the risk premium (RP).

5 Discussion and Conclusion

This paper presents an update of an earlier meta-analysis (Tol 2005) of the social cost of carbon. Using more data and more advanced statistical analysis, this paper confirms the findings of Tol (2005) that estimates of the social cost of carbon are driven to a large extent by the choice of the discount rate and equity weights; and that the more pessimistic estimates have not been subject to peer review. This paper also offers four new results. Firstly, there is a downward trend in the estimates of the social cost of carbon—even if the IPCC (Schneider et al. 2007) would like to believe the opposite. Secondly, the Stern Review (Stern et al. 2006) is an outlier—and its impact estimates are pessimistic even when compared to other studies in the gray literature and other estimates that use low discount rates. Thirdly, the uncertainty about the social cost of carbon is so large that the tails of the distribution may dominate the conclusions (Weitzman 2007b)—even though many of the high estimates have not been peer-reviewed and use unacceptably low discount rates. Fourthly, if everyone were to pay a carbon price equal to the social cost of carbon (but not reduce emissions much, as they cannot in the short-term), there is a fair chance that annual taxes would exceed annual income for many people. If the carbon price is a liability, this would imply bankruptcy. If the carbon price is a tax, this would imply complete collectivisation of the economy.

There are three implications. Firstly, greenhouse gas emission reduction today is justified. Even the most conservative assumption lead to positive estimates of the social cost of carbon (cf. Table 1) and the Pigou tax is thus greater than zero. Yohe et al. (2007) argue that there is reason to reduce greenhouse gas emissions further than recommended by cost-benefit analysis. The median of the Fisher-Tippett kernel density for peer-reviewed estimates with a 3% pure rate of time preference and without equity weights, is \$20/tC. This compares to a price of carbon permits of \$160/tC in the

European Union,⁸ and a zero price in most of the rest of the world. The case for intensification of climate policy outside the EU can be made with conservative assumptions. One does not have to rely on speculation as in Schneider et al. (2007) or dodgy analysis as in Stern et al. (2006). At the same time, current EU climate policy seems to fail the cost-benefit test unless one puts a heavy emphasis on risk and uses a very low discount rate (cf. Tol, 2007, for a more detailed discussion). Secondly, the uncertainty is so large that a considerable risk premium is warranted. With the conservative assumptions above, the mean equals \$23/tC and the certainty-equivalent \$25/tC. More importantly, there is a 1% probability that the social cost of carbon is greater than \$78/tC. This number rapidly increases if we use a lower discount rate—as may well be appropriate for a problem with such a long time horizon—and if we allow for the possibility that there is some truth in the scare-mongering of the gray literature. Thirdly, more research is needed into the economic impacts of climate change—to eliminate that part of the uncertainty that is due to lack of study, and to separate the truly scary impacts from the scare-mongering. Papers often conclude with a call for more research, and often this is a call for funding for the authors or a justification for further papers by the authors. In this case, however, quality research by newcomers in the field would be particularly welcome.

⁸ June 28, 2008; <http://www.eex.de/en>; <http://www.oanda.com/>

Appendix

Table A1: Estimates of the Social Cost of Carbon (SCC), and Characteristics of the Study (PR: peer-reviewed; IE: independent estimate; ME: correct estimation method; DM: dynamic model of vulnerability; SC: realistic scenario; CDR: consumption discount rate; P RTP: pure rate of time preference; EW: equity-weighted)

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	P RTP	EW
Nordhaus	1982	1.000	146.7	1	1	0	0	0	NA	1.0	0
Ayres & Walter	1991	1.000	119.0	1	1	0	0	0	3.0	1.0	0
Nordhaus	1991	1.000	26.8	1	1	0	0	0	3.0	1.0	0
Haradan	1992	1.000	7.3	1	1	0	0	0	4.0	2.0	0
Cline	1992	1.000	64.9	0	1	1	0	1	NA	NA	0
Hoymeyer & Gaertner	1992	1.000	1,666.7	0	1	0	0	1	0.0	-2.0	0
Haradan	1993	0.250	1.9	1	0	0	0	0	4.0	2.0	0
	1993	0.500	3.0	1	0	0	0	0	4.0	2.0	0
	1993	0.250	8.8	1	0	0	0	0	4.0	2.0	0
Nordhaus	1993	1.000	5.0	1	0	1	0	1	5.0	3.0	0
Peck & Teisberg	1993	1.000	10.0	1	0	1	0	1	5.0	3.0	0
Reilly & Richards	1993	0.500	14.3	1	0	1	0	0	5.0	3.0	0
	1993	0.500	21.2	1	0	1	0	0	5.0	3.0	0
Fankhauser	1994	1.000	20.3	1	1	1	0	1	NA	NA	0
Nordhaus	1994	1.000	5.3	0	1	1	0	1	5.0	3.0	0
Azar	1994	0.250	50.0	1	0	0	0	0	NA	0.0	0
	1994	0.500	200.0	1	0	0	0	0	NA	0.0	0
	1994	0.250	500.0	1	0	0	0	0	NA	0.0	0
Maddison	1995	1.000	16.5	1	0	1	0	1	5.0	3.0	0
Schauer	1995	0.500	8.3	1	1	1	0	1	4.9	2.3	0
	1995	0.500	112.5	1	1	1	0	1	4.9	2.3	0
Plambeck & Hope	1996	0.300	3.0	1	1	1	0	1	5.0	3.0	0
	1996	0.100	8.0	1	1	1	0	1	5.0	3.0	0
	1996	0.100	8.0	1	1	1	0	1	5.0	3.0	0
	1996	0.300	21.0	1	1	1	0	1	5.0	3.0	0
	1996	0.100	46.0	1	1	1	0	1	4.0	2.0	0
	1996	0.100	440.0	1	1	1	0	1	2.0	0.0	0
Azar & Sterner	1996	0.044	85.0	1	0	1	0	1	2.0	0.0	0
	1996	0.089	200.0	1	0	1	0	1	2.0	0.0	0
	1996	0.033	75.0	1	0	1	0	1	2.1	0.1	0
	1996	0.067	140.0	1	0	1	0	1	2.1	0.1	0
	1996	0.022	32.0	1	0	1	0	1	3.0	1.0	0
	1996	0.044	33.0	1	0	1	0	1	3.0	1.0	0
	1996	0.011	13.0	1	0	1	0	1	5.0	3.0	0
	1996	0.022	13.0	1	0	1	0	1	5.0	3.0	0
	1996	0.089	260.0	1	0	1	0	1	2.0	0.0	1

Table A1 continued

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	P RTP	EW
	1996	0.178	590.0	1	0	1	0	1	2.0	0.0	1
	1996	0.067	230.0	1	0	1	0	1	2.1	0.1	1
	1996	0.133	410.0	1	0	1	0	1	2.1	0.1	1
	1996	0.044	95.0	1	0	1	0	1	3.0	1.0	1
	1996	0.089	98.0	1	0	1	0	1	3.0	1.0	1
	1996	0.022	39.0	1	0	1	0	1	5.0	3.0	1
	1996	0.044	39.0	1	0	1	0	1	5.0	3.0	1
Downing et al.	1996	0.500	53.5	0	1	0	1	1	0.0	-2.0	0
	1996	0.500	18.3	0	1	0	1	1	0.0	-2.0	0
Hohmeyer	1996	1.000	800.0	0	0	0	0	1	0.0	-2.0	0
Hope & Maul	1996	0.100	7.0	1	1	1	0	0	4.0	2.0	0
	1996	1.000	24.0	1	1	1	0	0	4.0	2.0	0
	1996	0.800	5.0	1	1	1	0	1	4.0	2.0	0
	1996	0.100	29.0	1	1	1	0	0	4.0	2.0	0
Nordhaus & Yang	1996	1.000	6.2	1	1	1	0	1	5.0	3.0	0
Nordhaus & Popp	1997	0.900	11.6	1	0	1	0	1	5.0	3.0	0
	1997	0.100	6.3	1	0	1	0	1	5.0	3.0	0
Cline	1997	1.000	88.0	0	1	1	0	1	NA	NA	0
Eyre et al.	1999	0.500	170.0	0	0	1	1	1	1.0	-1.0	1
	1999	0.500	70.0	0	0	1	1	1	3.0	1.0	1
	1999	0.500	160.0	0	0	1	1	1	1.0	-1.0	1
	1999	0.500	74.0	0	0	1	1	1	3.0	1.0	1
Tol	1999	0.250	60.0	1	1	1	1	1	3.0	1.0	1
	1999	0.050	62.0	1	1	1	1	1	3.0	1.0	1
	1999	0.050	23.0	1	1	1	1	1	3.0	1.0	0
	1999	0.050	66.0	1	1	1	1	1	3.0	1.0	1
	1999	0.050	65.0	1	1	1	1	1	3.0	1.0	1
	1999	0.050	56.0	1	1	1	1	1	3.0	1.0	1
	1999	0.050	317.0	1	1	1	1	1	0.0	-2.0	1
	1999	0.010	243.0	1	1	1	1	1	0.0	-2.0	1
	1999	0.010	142.0	1	1	1	1	1	0.0	-2.0	0
	1999	0.010	360.0	1	1	1	1	1	0.0	-2.0	1
	1999	0.010	348.0	1	1	1	1	1	0.0	-2.0	1
	1999	0.010	288.0	1	1	1	1	1	0.0	-2.0	1
	1999	0.050	171.0	1	1	1	1	1	1.0	-1.0	1
	1999	0.010	172.0	1	1	1	1	1	1.0	-1.0	1
	1999	0.010	73.0	1	1	1	1	1	1.0	-1.0	0
	1999	0.010	192.0	1	1	1	1	1	1.0	-1.0	1
	1999	0.010	187.0	1	1	1	1	1	1.0	-1.0	1
	1999	0.010	156.0	1	1	1	1	1	1.0	-1.0	1
	1999	0.100	26.0	1	1	1	1	1	5.0	3.0	1

Table A1 continued

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	PRTP	EW
	1999	0.020	26.0	1	1	1	1	1	5.0	3.0	1
	1999	0.020	9.0	1	1	1	1	1	5.0	3.0	0
	1999	0.020	28.0	1	1	1	1	1	5.0	3.0	1
	1999	0.020	28.0	1	1	1	1	1	5.0	3.0	1
	1999	0.020	25.0	1	1	1	1	1	5.0	3.0	1
	1999	0.050	6.0	1	1	1	1	1	10.0	8.0	1
	1999	0.010	6.0	1	1	1	1	1	10.0	8.0	1
	1999	0.010	2.0	1	1	1	1	1	10.0	8.0	0
	1999	0.010	6.0	1	1	1	1	1	10.0	8.0	1
	1999	0.010	6.0	1	1	1	1	1	10.0	8.0	1
	1999	0.010	6.0	1	1	1	1	1	10.0	8.0	1
Roughgarden & Schneider	1999	1.000	40.4	1	1	1	0	1	5.0	3.0	0
Nordhaus & Boyer	2000	1.000	5.9	0	1	1	0	1	NA	NA	0
Tol & Downing	2000	0.100	26.1	0	0	1	1	1	3.0	1.0	1
	2000	0.100	3.5	0	0	1	1	1	3.0	1.0	0
	2000	1.000	45.8	0	0	1	1	1	3.0	1.0	1
	2000	0.800	5.1	0	0	1	1	1	3.0	1.0	0
Clarkson & Deyes	2002	1.000	101.5	0	0	1	0	1	3.0	1.0	1
Tol	2002	0.083	19.9	0	1	1	1	1	2.0	0.0	0
	2002	0.167	16.1	0	1	1	1	1	2.0	0.0	1
	2002	0.167	3.8	0	1	1	1	1	3.0	1.0	0
	2002	0.333	6.6	0	1	1	1	1	3.0	1.0	1
	2002	0.083	-6.6	0	1	1	1	1	5.0	3.0	0
	2002	0.167	-0.5	0	1	1	1	1	5.0	3.0	1
Newell & Pizer	2003	0.100	5.7	1	0	1	0	1	4.0	2.0	0
	2003	0.200	10.4	1	0	1	0	1	NA	2.0	0
	2003	0.200	6.5	1	0	1	0	1	NA	2.0	0
	2003	0.050	21.7	1	0	1	0	1	2.0	0.0	0
	2003	0.100	33.8	1	0	1	0	1	NA	0.0	0
	2003	0.100	23.3	1	0	1	0	1	NA	0.0	0
	2003	0.050	1.5	1	0	1	0	1	7.0	5.0	0
	2003	0.100	2.9	1	0	1	0	1	NA	5.0	0
	2003	0.100	1.8	1	0	1	0	1	NA	5.0	0
Pearce	2003	1.000	23.5	1	0	1	0	1	3.0	1.0	1
Uzawa	2003	1.000	160.7	0	1	0	0	0	NA	NA	NA
Mendelsohn	2003	1.000	1.5	0	1	0	0	0	5.0	3.0	0
Hope	2003	1.000	19.0	0	0	1	0	1	NA	3.0	0
Link & Tol	2004	0.165	79.0	1	1	1	1	1	NA	0.0	0
	2004	0.165	170.0	1	1	1	1	1	NA	0.0	1
	2004	0.165	25.2	1	1	1	1	1	NA	1.0	0
	2004	0.165	94.1	1	1	1	1	1	NA	1.0	1

Table A1 continued

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	PRTP	EW
	2004	0.165	5.1	1	1	1	1	1	NA	3.0	0
	2004	0.165	45.1	1	1	1	1	1	NA	3.0	1
	2004	0.002	75.6	1	1	1	1	1	NA	0.0	0
	2004	0.002	167.8	1	1	1	1	1	NA	0.0	1
	2004	0.002	24.4	1	1	1	1	1	NA	1.0	0
	2004	0.002	93.6	1	1	1	1	1	NA	1.0	1
	2004	0.002	5.0	1	1	1	1	1	NA	3.0	0
	2004	0.002	45.0	1	1	1	1	1	NA	3.0	1
Hohmeyer	2004	0.500	32.0	0	0	1	0	1	NA	1.0	0
	2004	0.500	590.0	0	0	1	0	1	NA	0.0	1
Cline	2004	0.900	128.0	0	0	1	0	1	NA	NA	0
	2004	0.050	450.0	0	0	1	0	1	NA	NA	0
	2004	0.050	10.0	0	0	1	0	1	NA	NA	0
Manne	2004	0.050	300.0	0	0	1	0	1	NA	NA	0
	2004	0.950	12.0	0	0	1	0	1	NA	NA	0
Hope	2005	1.000	21.0	0	1	1	0	1	NA	3.0	0
Ceronsky et al.	2005	0.238	58.0	0	0	1	1	1	NA	0.0	0
	2005	0.238	11.0	0	0	1	1	1	NA	1.0	0
	2005	0.238	-2.3	0	0	1	1	1	NA	3.0	0
	2005	0.238	18.0	0	0	1	1	1	NA	NA	0
	2005	0.001	54.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	11.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-2.5	0	0	1	1	1	NA	3.0	0
	2005	0.001	17.0	0	0	1	1	1	NA	NA	0
	2005	0.001	54.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	13.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-0.1	0	0	1	1	1	NA	3.0	0
	2005	0.001	20.0	0	0	1	1	1	NA	NA	0
	2005	0.001	54.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	10.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-2.5	0	0	1	1	1	NA	3.0	0
	2005	0.001	17.0	0	0	1	1	1	NA	NA	0
	2005	0.001	55.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	11.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-2.5	0	0	1	1	1	NA	3.0	0
	2005	0.001	18.0	0	0	1	1	1	NA	NA	0
	2005	0.001	58.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	12.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-2.3	0	0	1	1	1	NA	3.0	0
	2005	0.001	18.0	0	0	1	1	1	NA	NA	0
	2005	0.001	73.0	0	0	1	1	1	NA	0.0	0

Table A1 continued

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	P RTP	EW
Hope	2005	0.001	16.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-1.6	0	0	1	1	1	NA	3.0	0
	2005	0.001	24.0	0	0	1	1	1	NA	NA	0
	2005	0.001	94.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	21.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	-0.7	0	0	1	1	1	NA	3.0	0
	2005	0.001	30.0	0	0	1	1	1	NA	NA	0
	2005	0.001	330.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	89.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	17.0	0	0	1	1	1	NA	3.0	0
	2005	0.001	100.0	0	0	1	1	1	NA	NA	0
	2005	0.001	1,500.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	360.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	75.0	0	0	1	1	1	NA	3.0	0
	2005	0.001	270.0	0	0	1	1	1	NA	NA	0
	2005	0.001	2,400.0	0	0	1	1	1	NA	0.0	0
	2005	0.001	580.0	0	0	1	1	1	NA	1.0	0
	2005	0.001	120.0	0	0	1	1	1	NA	3.0	0
	2005	0.001	360.0	0	0	1	1	1	NA	NA	0
	2005	0.167	43.0	0	0	1	0	1	NA	3.0	1
	2005	0.167	35.0	0	0	1	0	1	NA	3.0	1
	2005	0.167	31.0	0	0	1	0	1	NA	3.0	0
	2005	0.167	46.0	0	0	1	0	1	NA	3.0	1
	2005	0.167	37.0	0	0	1	0	1	NA	3.0	1
	2005	0.167	32.0	0	0	1	0	1	NA	3.0	0
Downing et al.	2005	1.000	50.8	0	0	0	0	0	NA	NA	1
Guo et al.	2006	0.016	58.0	1	0	1	1	1	NA	0.0	0
	2006	0.016	11.0	1	0	1	1	1	NA	1.0	0
	2006	0.016	-2.3	1	0	1	1	1	NA	3.0	0
	2006	0.143	18.0	1	0	1	1	1	NA	NA	0
	2006	0.008	6.6	1	0	1	1	1	3.5		0
	2006	0.143	88.0	1	0	1	1	1	NA	NA	0
	2006	0.008	2.1	1	0	1	1	1	4.0		0
	2006	0.214	88.0	1	0	1	1	1	NA	NA	0
	2006	0.008	2.1	1	0	1	1	1	4.0		0
	2006	0.036	185.0	1	0	1	1	1	NA	0.0	0
	2006	0.036	29.0	1	0	1	1	1	NA	1.0	0
	2006	0.036	-1.3	1	0	1	1	1	NA	3.0	0
	2006	0.036	85.0	1	0	1	1	1	NA	0.0	0
	2006	0.036	15.0	1	0	1	1	1	NA	1.0	0
	2006	0.036	-2.1	1	0	1	1	1	NA	3.0	0
	2006	0.214	35.0	1	0	1	1	1	NA	NA	0

Table A1 continued

Author	Year	Weight	SCC	PR	IE	ME	DM	SC	CDR	P RTP	EW
Wahba & Hope	2006	0.200	19.0	1	0	1	0	1	NA	3.0	0
	2006	0.200	14.0	1	0	1	0	1	NA	3.0	0
	2006	0.100	47.0	1	0	1	0	1	NA	2.0	0
	2006	0.100	145.0	1	0	1	0	1	NA	1.0	0
	2006	0.100	30.0	1	0	1	0	1	NA	2.0	0
	2006	0.100	91.0	1	0	1	0	1	NA	1.0	0
	2006	0.100	29.0	1	0	1	0	1	NA	3.0	0
	2006	0.100	21.0	1	0	1	0	1	NA	3.0	0
Hope	2006	1.000	19.0	1	0	1	0	1	NA	3.0	0
Stern et al.	2006	1.000	314.0	0	0	1	0	1	NA	0.0	1

References

- Anderson, D. (2007), "The Stern Review and the Costs of Climate Change Mitigation -- A Response to the "Dual Critique" and the Misrepresentations of Tol and Yohe", *World Economics*, 8, (1), 211-219.
- Anthoff, D., C. Hepburn and R.S.J. Tol (forthcoming), "Equity Weighing and the Marginal Damage Costs of Climate Change", *Ecological Economics*.
- Arrow, K.J. (2007), "Global Climate Change: A Challenge to Policy", *Economists' Voice* (June), 1-5.
- Ayres, R.U. and J. Walter (1991), "The Greenhouse Effect: Damages, Costs and Abatement", *Environmental and Resource Economics*, 1, 237-270.
- Azar, C. and T. Sterner (1996), "Discounting and Distributional Considerations in the Context of Global Warming", *Ecological Economics*, 19, 169-184.
- Azar, C. (1994), "The Marginal Cost of CO₂ Emissions", *Energy*, 19, (12), 1255-1261.
- Byatt, I., I. Castles, I.D. Goklany, D. Henderson, N. Lawson, R. McKittrick, J. Morris, A. Peacock, C. Robinson, and R. Skidelsky (2006), "The Stern Review: A Dual Critique -- Economic Aspects", *World Economics*, 7, (4), 199-229.
- Carter, R. M., C.R. de Freitas, I.D. Goklany, D. Holland, and R.S. Lindzen (2006), "The Stern Review: A Dual Critique -- The Science", *World Economics*, 7, (4), 167-198.
- CEC (2005), Winning the Battle Against Global Climate Change, Commission of the European Communities, Brussels, COM(2005) 35 final.
- CEC (2005), Winning the Battle Against Global Climate Change -- Background Paper, Commission of the European Communities, Brussels.
- Ceronsky, M., D. Anthoff, C. Hepburn and R.S.J. Tol (2005), Checking the Price Tag on Catastrophe: The Social Cost of Carbon under Non-linear Climate Response, Research unit Sustainability and Global Change FNU-87, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg.
- Clarkson, R. and K. Deyes (2002), Estimating the Social Cost of Carbon Emissions, The Public Enquiry Unit - HM Treasury, London, Working Paper 140.
- Cline, W.R. (2004), Meeting the Challenge of Global Warming, National Environmental Assessment Institute, Copenhagen.
- Cline, W.R. (1997), "Modelling Economically Efficient Abatement of Greenhouse Gases", in *Environment, Energy, and Economy*, Y. Kaya and K. Yokobori (eds.), United Nations University Press, Tokyo, pp. 99-122.
- Cline, W.R. (1992), The Economics of Global Warming, Institute for International Economics, Washington, D.C.
- Dasgupta, P. (2007), "Commentary: The Stern Review's Economics of Climate Change", *National Institute Economic Review*, 199, 4-7.
- Dietz, S., C.W. Hope, N.H. Stern, and D. Zenghelis (2007), "Reflections on the Stern Review (1) A Robust Case for Strong Action to Reduce the Risks of Climate Change", *World Economics*, 8, (1), 121-168.

- Dietz, S., D. Anderson, N.H. Stern, C. Taylor, and D. Zenghelis (2007), "Right for the Right Reasons", *World Economics*, 8, (2), 229-258.
- Downing, T.E., N. Eyre, R. Greener, and D. Blackwell (1996), *Projected Costs of Climate Change for Two Reference Scenarios and Fossil Fuel Cycles*, Environmental Change Unit, Oxford.
- Downing, T.E., D. Anthoff, R. Butterfield, M. Ceronisky, M.J. Grubb, J. Guo, C.J. Hepburn, C.W. Hope, A. Hunt, A. Li, A. Markandya, S. Moss, A. Nyong, R.S.J. Tol, and P. Watkiss (2005), Social Cost of Carbon: A Closer Look at Uncertainty, Department of Environment, Food and Rural Affairs, London.
- Eyre, N., T.E. Downing, R. Hoekstra, and K. Rennings (1999), *Externalities of Energy*, Vol 8: Global Warming, Office for Official Publications of the European Communities, Luxembourg.
- Fankhauser, S. and R.S.J. Tol (1996), "Climate Change Costs -- Recent Advancements in the Economic Assessment", *Energy Policy*, 24, (7), 665-673.
- Fankhauser, S. (1994), "The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach", *Energy Journal*, 15, (2), 157-184.
- Fankhauser, S. (1995), Valuing Climate Change - The Economics of the Greenhouse, 1 edn, EarthScan, London. Further information.
- Fankhauser, S., R.S.J. Tol, and D.W. Pearce (1997), "The Aggregation of Climate Change Damages: A Welfare Theoretic Approach", *Environmental and Resource Economics*, 10, 249-266.
- Fankhauser, S., R.S.J. Tol and D.W. Pearce (1998), "Extensions and Alternatives to Climate Change Impact Valuation: On the Critique on IPCC WG3's Impact Estimates", *Environment and Development Economics*, 3, 59-81.
- Gollier, C. (2002), "Time Horizon and the Discount Rate", *Journal of Economic Theory*, 107, 463-473.
- Guo, J., C.J. Hepburn, R.S.J. Tol, and D. Anthoff (2006), "Discounting and the Social Cost of Climate Change: A Closer Look at Uncertainty", *Environmental Science & Policy*, 9, 205-216.
- Hamid, L., N.H. Stern, and C. Taylor (2007), "Reflections on the Stern Review (2) A Growing International Opportunity to Move Strongly on Climate Change", *World Economics*, 8, (1), 169-186.
- Haraden, J. (1992), "An Improved Shadow Price for CO₂", *Energy*, 17, (5), 419-426.
- Haraden, J. (1993), "An Updated Shadow Price for CO₂", *Energy*, 18, (3), 303-307.
- Hohmeyer, O. (1996), "Social Costs of Climate Change -- Strong Sustainability and Social Costs", in *Social Costs and Sustainability -- Valuation and Implementation in the Energy and Transport Sector*, O. Hohmeyer, R.L. Ottinger, and K. Rennings (eds.), Springer, Berlin, pp. 61-83.
- Hohmeyer, O. and M. Gaertner (1992), *The Costs of Climate Change -- A Rough Estimate of Orders of Magnitude*, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Karlsruhe.
- Hope, C.W. (2003), The Marginal Impacts of CO₂, CH₄ and SF₆ Emissions, Judge Institute of Management, Cambridge, WP10/2003.

- Hope, C.W. (2005), Exchange Rates and the Social Cost of Carbon, Judge Institute of Management, Cambridge, WP05/2005.
- Hope, C.W. (2005), "The Climate Change Benefits of Reducing Methane Emissions", *Climatic Change*, 68, 21-39.
- Hope, C.W. (2006), "The Marginal Impact of CO₂ from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern", *Integrated Assessment Journal*, 6, (1), 19-56.
- Hope, C.W. and P. Maul (1996), "Valuing the Impact of CO₂ Emissions", *Energy Policy*, 24, (3), 211-219.
- Link, P.M. and R.S.J. Tol (2004), "Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: an Application of FUND", *Portuguese Economic Journal*, 3, 99-114.
- Maddison, D.J. (1995), "A Cost-Benefit Analysis of Slowing Climate Change", *Energy Policy*, 23, (4/5), 337-346.
- Maddison, D.J. (2003), "The Amenity Value of the Climate: The Household Production Function Approach", *Resource and Energy Economics*, 25, 155-175.
- Manne, A.S. (2004), Global Climate Change: An Opponent's Notes, Copenhagen Consensus 2004.
- Mendelsohn, R.O. (2003), The Social Cost of Carbon: An Unfolding Value, paper presented at the DEFRA International Seminar on the Social Cost of Carbon, London, July 7.
- Mendelsohn, R.O. (2006), "A Critique of the Stern Report", *Regulation* (Winter 2006/2007), 42-46.
- Mendelsohn, R.O., W. Morrison, M.E. Schlesinger, and N.G. Andronova (2000), "Country-specific Market Impacts of Climate Change", *Climatic Change*, 45, 553-569.
- Newell, R.G. and W.A. Pizer (2003), "Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations?", *Journal of Environmental Economics and Management*, 46, 52-71.
- Nordhaus, W.D. (1982), "How Fast Should We Graze the Global Commons?", *American Economic Review*, 72, (2), 242-246.
- Nordhaus, W.D. (1991), "To Slow or Not to Slow: The Economics of the Greenhouse Effect", *Economic Journal*, 101, 920-937.
- Nordhaus, W.D. (1993), "Rolling the 'DICE': An Optimal Transition Path for Controlling Greenhouse Gases", *Resource and Energy Economics*, 15, 27-50.
- Nordhaus, W.D. (1994), Managing the Global Commons: The Economics of Climate Change, The MIT Press, Cambridge.
- Nordhaus, W.D. (2006), "Geography and Macroeconomics: New Data and New Findings", *Proceedings of the National Academy of Science*.
- Nordhaus, W.D. (2007a), "Critical Assumptions in the Stern Review on Climate Change", *Science*, 317, 201-202.
- Nordhaus, W.D. (2007b), "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, 45, (3), 686-702.

- Nordhaus, W.D. and J.G. Boyer (2000), Warming the World: Economic Models of Global Warming, The MIT Press, Cambridge, Massachusetts -- London, England. Further information.
- Nordhaus, W.D. and D. Popp (1997), “What is the Value of Scientific Knowledge? An Application to Global Warming Using the PRICE Model”, *Energy Journal*, 18, (1), 1-45.
- Nordhaus, W.D. and Z. Yang (1996), “RICE: A Regional Dynamic General Equilibrium Model of Optimal Climate-Change Policy”, *American Economic Review*, 86, (4), 741-765.
- Pearce, D.W. (2003), “The Social Cost of Carbon and its Policy Implications”, *Oxford Review of Economic Policy*, 19, (3), 1-32.
- Pearce, D.W., W.R. Cline, A.N. Achanta, S. Fankhauser, R.K. Pachauri, R.S.J. Tol, and P. Vellinga (1996), “The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control”, in *Climate Change 1995: Economic and Social Dimensions -- Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, J.P. Bruce, H. Lee, and E.F. Haites (eds.), Cambridge University Press, Cambridge, pp. 179-224.
- Peck, S.C. and T.J. Teisberg (1993), “CO2 Emissions Control - Comparing Policy Instruments”, *Energy Policy*, 15, 222-230.
- Plambeck, E.L. and C.W. Hope (1996), “PAGE95 -- An Updated Valuation of the Impacts of Global Warming”, *Energy Policy*, 24, (9), 783-793.
- Rehdanz, K. and D.J. Maddison (2005), “Climate and Happiness”, *Ecological Economics*, 52, 111-125.
- Reilly, J.M. and K.R. Richards (1993), “Climate Change Damage and the Trace Gas Index Issue”, *Environmental and Resource Economics*, 3, 41-61. Further information in IDEAS/RePEc.
- Roughgarden, T. and S.H. Schneider (1999), “Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes”, *Energy Policy*, 27, 415-429.
- Schauer, M.J. (1995), “Estimation of the Greenhouse Gas Externality with Uncertainty”, *Environmental and Resource Economics*, 5, (1), 71-82.
- Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadya, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez, and F. Yamin (2007), “Assessing Key Vulnerability and the Risk from Climate Change”, in *Climate Change 2007: Impacts, Adaptation and Vulnerability -- Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry et al. (eds.), Cambridge University Press, Cambridge, pp. 779-810. Further information.
- Smith, J.B., H.-J. Schellnhuber, M.Q. Mirza, S. Fankhauser, R. Leemans, L. Erda, L. Ogallo, B. Pittock, R.G. Richels, C. Rosenzweig, U. Safriel, R.S.J. Tol, J.P. Weyant, and G.W. Yohe (2001), “Vulnerability to Climate Change and Reasons for Concern: A Synthesis”, in *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, J.J. McCarthy et al. (eds.), Press Syndicate of the University of Cambridge, Cambridge, UK, pp. 913-967. Further information.
- Spash, C.L. (2007), “The Economics of Climate Change Impacts a la Stern: Novel and Nuanced to Rhetorically Restricted?”, *Ecological Economics*, 63, 706-713.
- Stern, N.H. and C. Taylor (2007), “Climate Change: Risks, Ethics and the Stern Review”, *Science*, 317, 203-204.

- Stern, N.H., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, D. Crane, S. Cruickshank, S. Dietz, N. Edmonson, S.-L. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M. Stock, C. Taylor, T. Vernon, H. Wanjie, and D. Zenghelis (2006), Stern Review: The Economics of Climate Change, Cambridge University Press, Cambridge.
- Tol, R.S.J. (1995), "The Damage Costs of Climate Change Toward More Comprehensive Calculations", *Environmental and Resource Economics*, 5, 353-374.
- Tol, R.S.J. (1999), "The Marginal Costs of Greenhouse Gas Emissions", *Energy Journal*, 20, (1), 61-81.
- Tol, R.S.J. (2002), "Estimates of the Damage Costs of Climate Change -- Part 1: Benchmark Estimates", *Environmental and Resource Economics*, 21, 47-73.
- Tol, R.S.J. (2002), "Welfare Specifications and Optimal Control of Climate Change: An Application of FUND", *Energy Economics*, 24, 367-376.
- Tol, R.S.J. (2003), "Is the Uncertainty about Climate Change Too Large for Expected Costbenefit Analysis?", *Climatic Change*, 56, 265-289.
- Tol, R.S.J. (2005), "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties", *Energy Policy*, 33, 2064-2074.
- Tol, R.S.J. (2006), "The Stern Review of the Economics of Climate Change: A Comment", *Energy & Environment*, 17, (6), 977-981.
- Tol, R.S.J. (2007), "Europe's Long-Term Climate Target: A Critical Evaluation", *Energy Policy*, 35, 424-432. Further information.
- Tol, R.S.J. and T.E. Downing (2000), *The Marginal Costs of Climate Changing Gases*, Institute for Environmental Studies D00/08, Vrije Universiteit, Amsterdam.
- Tol, R.S.J. and R. Verheyen (2004), "State Responsibility and Compensation for Climate Change Damages -- A Legal and Economic Assessment", *Energy Policy*, 32, 1109-1130.
- Tol, R.S.J. and G.W. Yohe (2006), "A Review of the Stern Review", *World Economics*, 7, (4), 233-250.
- Tol, R.S.J. and G.W. Yohe (2007), "A Stern Reply to the Reply to the Review of the Stern Review", *World Economics*, 8 (2).
- Tol, R.S.J. and G.W. Yohe (2007), "Infinite Uncertainty, Forgotten Feedbacks, and Cost-Benefit Analysis of Climate Change", *Climatic Change*, 83, 429-442.
- Uzawa, H. (2003), Economic Theory and Global Warming, Cambridge University Press, Cambridge, UK.
- Wahba, M. and C.W. Hope (2006), "The Marginal Impact of Carbon Dioxide under Two Scenarios of Future Emissions", *Energy Policy*, 34, 3305-3316.
- Weitzman, M.L. (2001), "Gamma Discounting", *American Economic Review*, 91, (1), 260-271.
- Weitzman, M.L. (2007a), "A Review of the Stern Review on the Economics of Climate Change", *Journal of Economic Literature*, 45, (3), 703-724.
- Weitzman, M.L. (2007b), The Role of Uncertainty in the Economics of Catastrophic Climate Change, mimeo.

- Yohe, G.W. (2006), “Some Thoughts on the Damage Estimates Presented in the Stern Review -- An Editorial”, *Integrated Assessment Journal*, 6, (3), 65-72.
- Yohe, G.W. and R.S.J. Tol (2006), “The Stern Review: Implications for Climate Change”, *Environment*, 49, (2), 36-42.
- Yohe, G.W., R.S.J. Tol, and D. Murphy (2007), “On Setting Near-Term Climate Policy while the Dust Begins to Settle -- The Legacy of the Stern Review”, *Energy & Environment*, 18, (5), 621-633.

Please note:

You are most sincerely encouraged to participate in the open assessment of this article. You can do so by either rating the article on a scale from 1 (bad) to 5 (excellent) or by posting your comments.

Please go to:

www.economics-ejournal.org/economics/journalarticles/2008-25

The Editor