UNIVERSITY OF CAMBRIDGE
Judge Business School

Working Paper Series

8/2011

New Insights from the PAGE09 Model: The Social Cost of CO2

C. Hope

Cambridge Judge Business School Working Papers

These papers are produced by Cambridge Judge Business School, University of Cambridge. They are circulated for discussion purposes only. Their contents should be considered preliminary and are not to be quoted without the authors' permission.

Cambridge Judge Business School author contact details are as follows:

Dr Chris Hope
Cambridge Judge Business School
University of Cambridge
c.hope@jbs.cam.ac.uk

Please address enquiries about the series to:

Research Manager
Cambridge Judge Business School
Trumpington Street
Cambridge CB2 1AG
UK

Tel: 01223 760546
Fax: 01223 339701
Email: research-support@jbs.cam.ac.uk

New insights from the PAGE09 model: The social cost of CO2

Chris Hope

July 2011

Abstract

PAGE09 is an updated version of the PAGE2002 integrated assessment model (Hope, 2011a). The default PAGE09 model gives a mean estimate of the social cost of CO2 (SCCO2) of $106 per tonne of CO2, compared to $81 from the PAGE2002 model used in the Stern review (Stern, 2007). The main reasons for the difference are the valuation by a representative agent from the EU, instead of the world as a whole , which increases the mean value by a factor of 4.3, a higher range for the discount rate, which decreases the mean value by a factor of 2.7, the use of the A1B socio-economic scenario, rather than A2, which decreases the mean value by a factor of 2.5, a higher range for the climate sensitivity, which increase the mean value by a factor of 1.5, and a lower assumption about the effectiveness of adaptation, which increases the mean value by a factor of 1.3. Other structural and parametric changes in moving from the PAGE2002 to the PAGE09 model decrease the mean value by a factor of 1.3

Introduction

PAGE09 is an updated version of the PAGE2002 integrated assessment model (Hope, 2011a). PAGE2002 was used to value the impacts and calculate the social cost of CO2 in the Stern review (Stern, 2007) and the Asian Development Bank's review of climate change in Southeast Asia (ADB, 2009), and value the impacts and costs in the Eliasch review of deforestation (Eliasch, 2008). The PAGE2002 model is described fully in Hope, 2006a and Hope, 2008.

The best known result from the PAGE2002 model is the mean social cost of CO2 of $85 (in the year 2001 in year 2000 dollars) per tonne of CO2, presented in the Stern review (Stern, 2007). This was towards the upper end of estimates at the time (Tol, 2002). Its magnitude was explained by the low discount rate used in the Stern review, and the inclusion of a full representation of uncertainty (Dietz et al, 2007).

The update of the PAGE model from PAGE2002 to PAGE09 has been made to take account of the latest scientific and economic information, primarily in the 4th Assessment Report of the IPCC (IPCC, 2007). Hope, 2011a describes the most important scientific, impact, emission and adaptation updates in the latest default version of the model, PAGE09 v1.7, including a full set of the model equations.

Hope, 2011b gives the result from the default PAGE09 model that is of most interest for setting prices on CO2 emissions: the amount by which the NPV of impacts increases if one more tonne of CO2 is emitted, or decreases if one less tonne is emitted – the social cost of CO2 (SCCO2). That paper shows that if emissions follow the SRES A1B scenario (Nakicenovic and Swart, 2000), the mean SCCO2 for one extra tonne of emissions in 2009 is about $102 per tonne of CO2, with a 5% to 95% range of about $10 to $270, all in $US(2005).

This result seems superficially to be quite close to the mean result of $85 per tonne of CO2 in the Stern review, particularly if that result is updated to 2009 and expressed in $2005. The purpose of this paper is to examine whether that superficial similarity stands up to more rigorous scrutiny, and to explain any differences that become apparent.

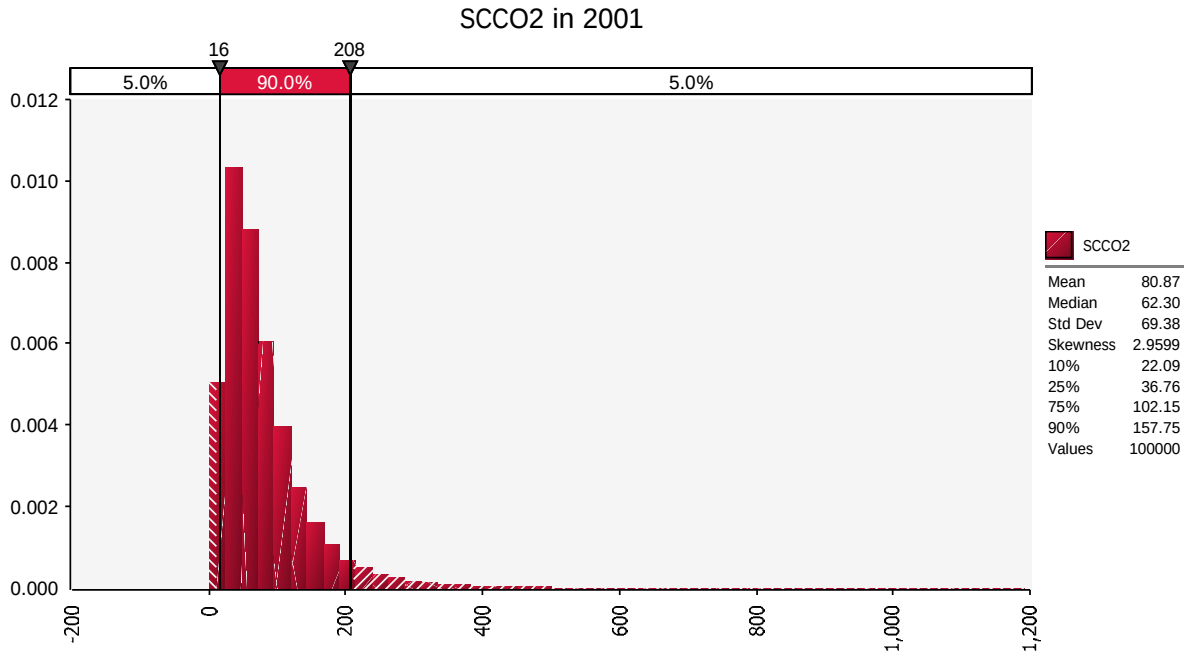
The SCCO2 from the PAGE2002 model

Figure 1 shows the full distribution of the SCCO2 using the same inputs that led to the mean value of $85 quoted in the Stern review (Stern, 2007). The values on the vertical axis of all the distributions in this paper have no meaning; the scale simply ensures that the integrated area under the curve is 1.

The actual text in the Stern review is "Preliminary calculations adopting the approach to valuation taken in this Review suggest that the social cost of carbon today, if we remain on a BAU trajectory, is of the order of $85 per tonne of CO2" (Stern, 2007, exec summary, p xvi). As can be seen from figure 1, with a full calculation of 100000 runs, the mean value is more accurately represented as $81 per

tonne of CO2. This result assumes that GDP, population and emissions follow the SRES A2 scenario (Nakicenovic and Swart, 2000), as in the Stern review.

Figure 1 The SCCO2 from the PAGE2002 model using Stern review inputs



The 5 – 95% range is $16 – 208, and the standard deviation of the result is $70, so the standard error of the mean is $70/sqrt(100000), which is about $0.25. So another 100000 runs would be 95% sure to produce a mean value within about $0.5 per tonne of the mean value shown in figure 1. The appropriate level of precision for reporting the SCCO2 results is thus to the nearest integer.

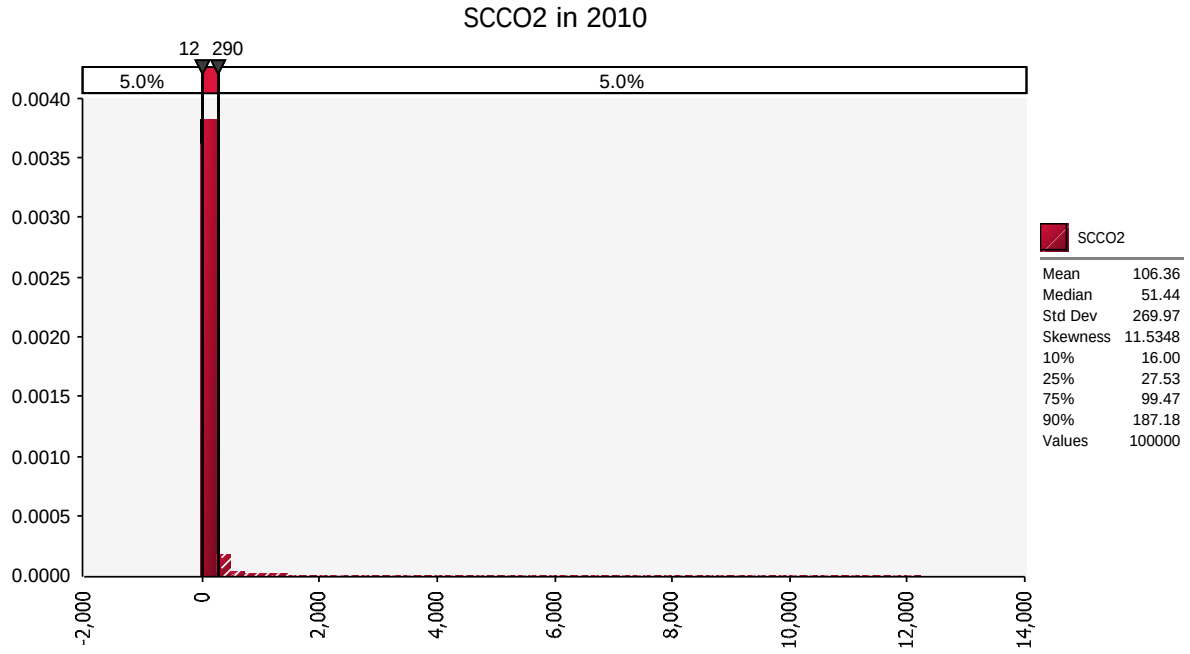
The most obvious feature of the distribution is its large positive skewness, with a possibility of an SCCO2 much higher than the mean value, up to about $1000 per tonne of CO2. These high values result when the small increase in emissions brings forward the date at which a discontinuity, such as the melting of the Greenland or West Antarctic ice sheets, becomes a possibility (Lenton et al, 2008).

The SCCO2 from the PAGE09 model

Figure 2 shows the full distribution of the SCCO2 from the current default PAGE09 model, version 1.7. The mean value is $106 per tonne of CO2, with a 5 – 95% range of $12 – 290. This assumes GDP, population and emissions follow the A1B scenario. It is slightly higher than the mean value of $102 reported in Hope, 2011b because it is for one extra tonne of emissions in 2010, not 2009.

The standard deviation of the result is $270, so the standard error of the mean is $270/sqrt(100000), which is about $0.75. So another 100000 runs would be 95% sure to produce a mean value within about $1.5 per tonne of the mean value shown in figure 2.

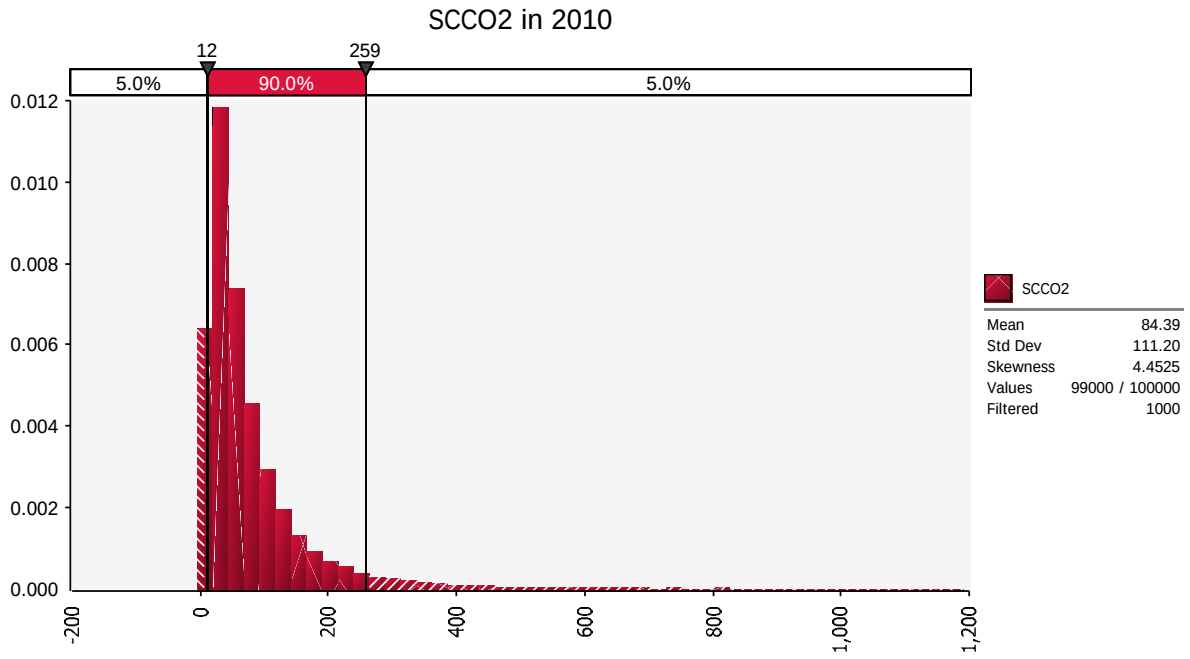
Figure 2 The SCCO2 from the PAGE09 default model



The positive skewness of the distribution is even more pronounced than for the distribution from PAGE2002, with a few values as high as about $10000 per tonne of CO2. Unlike the PAGE2002 model, the PAGE09 model keeps track of whether a discontinuity has actually been triggered, not just how likely one is to occur. These high values result when the small increase in emissions brings forward the date at which a discontinuity, such as the melting of the Greenland or West Antarctic ice sheets, has actually been triggered.

The skewness is so extreme that it is difficult to see the shape of the distribution when all the values are included. So figure 3 shows the same result but with the top 1% of values omitted.

Figure 3 The SCCO2 from the PAGE09 default model, top 1% of values omitted

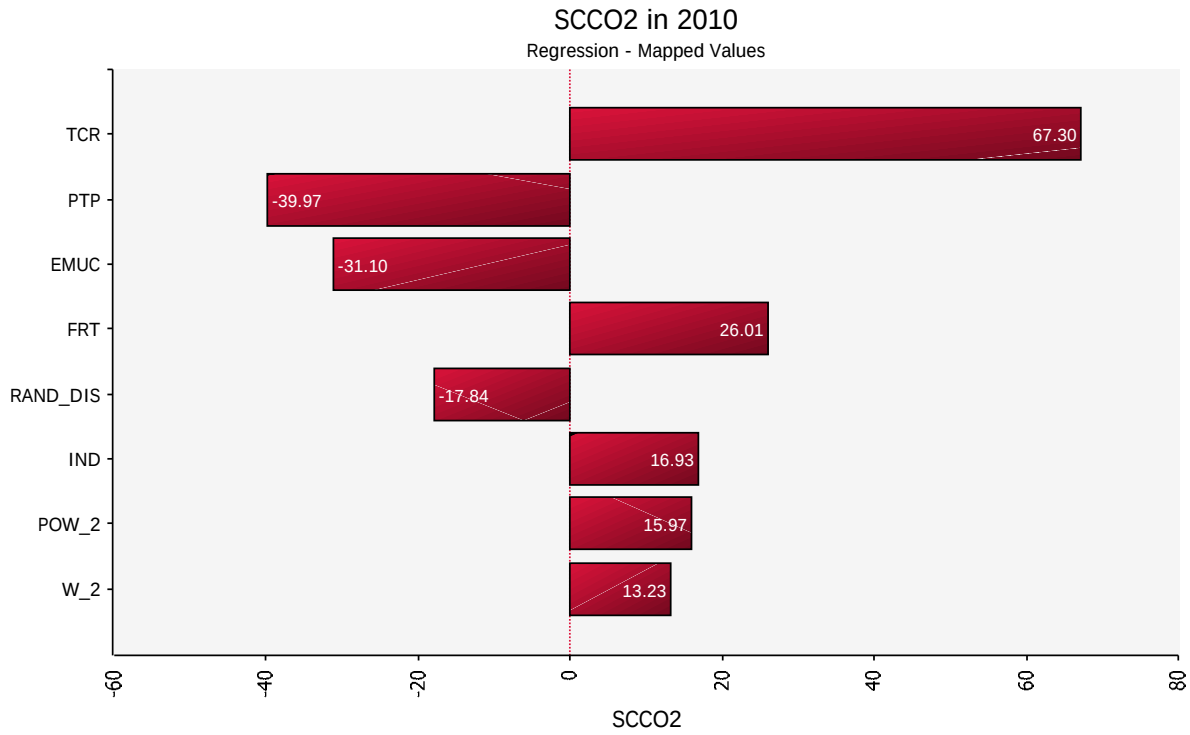


With the top 1% of values omitted, the PAGE09 distribution is much closer in shape to the PAGE2002 result, with similar values for the mean, standard deviation and skewness. Comparing the mean value of $84 per tonne with the mean value of $106 when all runs are included shows that the top 1% of runs contribute $22, or about 20%, to the mean SCCO2 value in the default PAGE09 model. This confirms the importance of properly representing uncertainty when making estimates of the SCCO2.

Major influences on the SCCO2

Figure 4 shows the amount by which the SCCO2 increases if the eight most important influences on the SCCO2 increase by one standard deviation. See Hope, 2011b for a full discussion of the input values to the default PAGE09 model.

Figure 4 Major influences on the SCCO2 from the PAGE09 default model



The most important influence is one of the components of the climate sensitivity. An increase in the transient climate response (TCR) by one standard deviation increases the SCCO2 by about $67. As the TCR has a triangular distribution with minimum value 1, mode 1.3 and maximum value 2.8 degC, its standard deviation is 0.4 degC.

Next are the pure time preference (PTP) rate and the equity weights (EMUC), and this time the signs of the influences are negative, with an increase in PTP or EMUC of one standard deviation, about 0.4% per year and 0.3 respectively, reducing the SCCO2 by about $40 and about $30 respectively. A higher PTP rate means that impacts that occur in the future have a lower NPV. A higher EMUC means that impacts that occur in the future, when consumption per capita is on average higher than today's consumption per capita in the EU, are weighted less. The implication of these results is that a PTP rate of 0.1% per year and an EMUC of 1, as used in Stern, 2007, would increase the mean SCCO2 by about $115, to over $220 per tonne of CO2.

An increase in the feedback response time (FRT) by one standard deviation, or about 11 years, increases the SCCO2 by about $26. It might be thought that the sign of this influence should be negative, as a longer response time means the Earth takes longer on average to respond to higher radiative forcing, but in fact, if the TCR is fixed, a higher value for FRT means a higher value for the climate sensitivity, and so a larger response to higher concentrations of CO2 overall.

The next most important influence is an internal variable in the model, a uniform random number between 0 and 1 which the probability of a discontinuity has to exceed for a discontinuity to be triggered. If this increases by one standard deviation, about 0.28, the SCCO2 is reduced by about $18. This shows that the possibility of a large-scale discontinuity does make a major contribution to the value of the SCCO2 in the A1B scenario, even though any discontinuity is very unlikely to be triggered in the near future.

Increasing (ie making less negative) the indirect sulphate effect (IND) by 0.16 W/m2 for a doubling of sulphate concentration increases the SCCO2 by about $17; increasing the exponent of the power function linking non-economic impacts to temperature (POW_2) by 0.3 increases the SCCO2 by $16, and increasing the weight on non-economic impacts (W_2) by one standard deviation, about 0.2% of GDP, increases the SCCO2 by about $13.

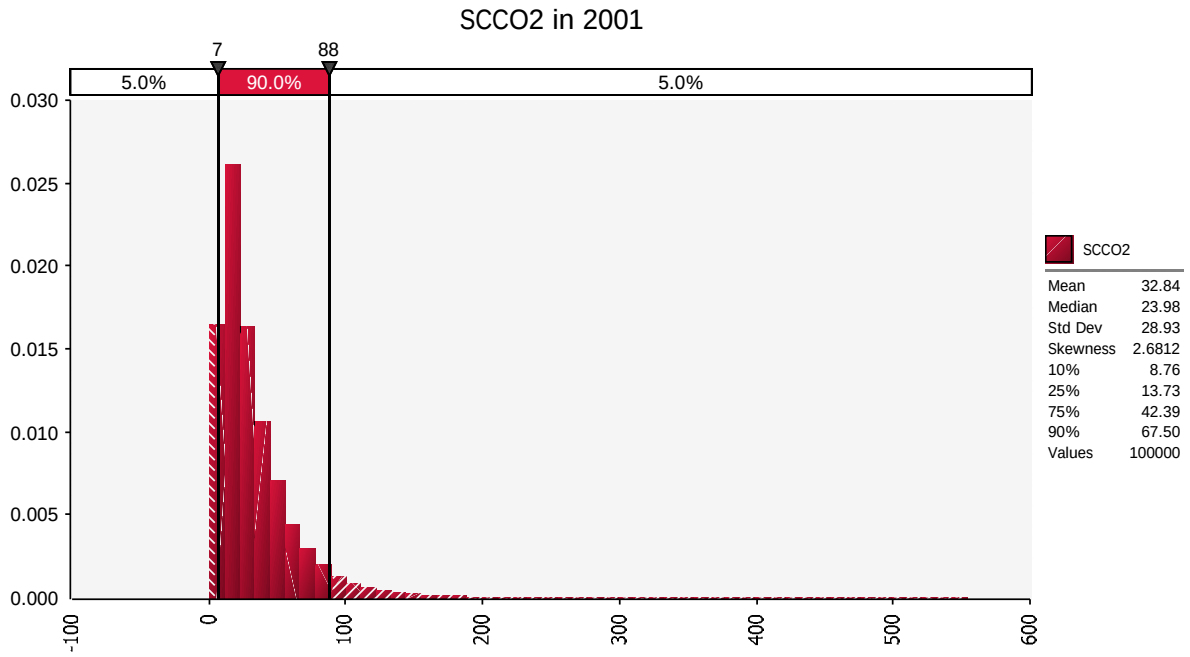
All of these influences have the sign that would be expected. They are very useful in guiding the investigation to discover how and why the SCCO2 differs between the PAGE2002 and PAGE09 models.

Comparing the results from the PAGE2002 and PAGE09 models

Business as usual scenario

The first difference between the version of PAGE2002 used in the Stern review, and the default version of the PAGE09 model is that the PAGE2002 model uses the IPCC SRES A2 scenario and the PAGE09 model uses A1B as its business as usual scenario (Nakicenovic and Swart, 2000). Using the PAGE2002 model with all inputs as for the Stern review, but with the A1B scenario instead of the A2 scenario gives the SCCO2 distribution shown in figure 5. The mean value is $33 per tonne of CO2, with a 5 – 95% range of $7 – 88.

Figure 5 The SCCO2 from the PAGE2002 model using Stern review inputs, A1B scenario



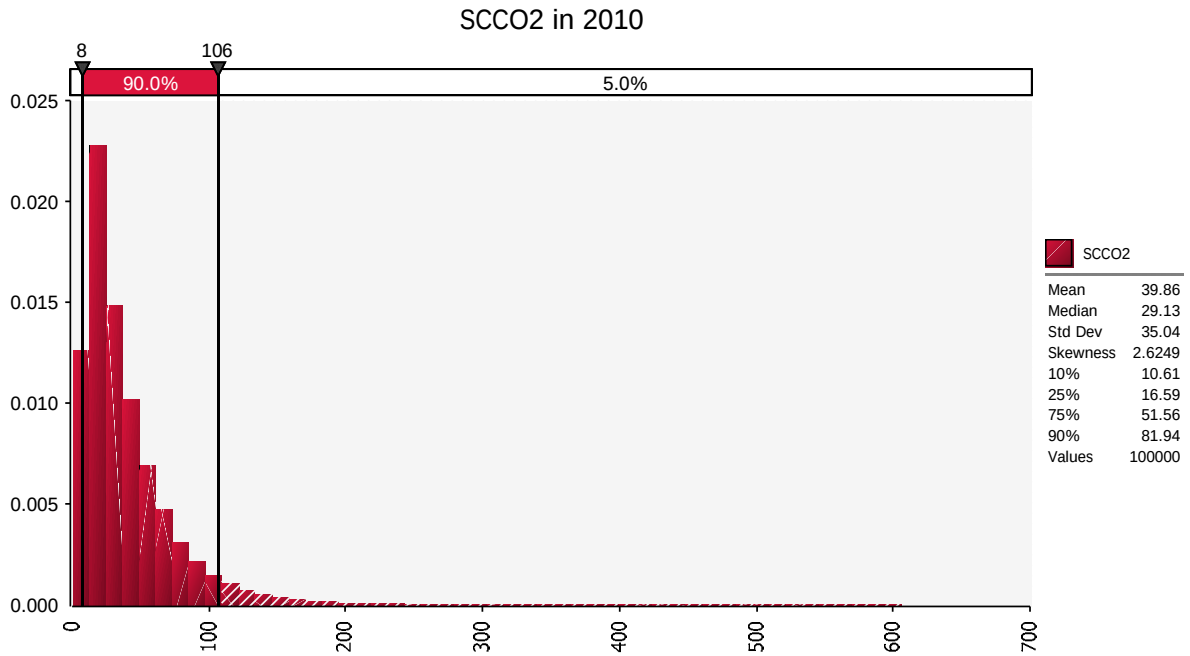
This is considerably lower than for the A2 scenario shown in figure 1, which had a mean value of $81, and might seem to contradict the findings of Hope, 2006b that the SCCO2 calculated by PAGE2002 is largely insensitive to the emissions scenario upon which the extra tonne of emissions is

superimposed. In fact it does not, as the reduction in mean value from $81 to $33 is mainly due to the lower population assumptions in scenario A1B; by 2100 the global population is only about half the value in scenario A2, 7 billion rather than 14 billion. Running PAGE2002 with the emissions from scenario A1B but the GDP and population from scenario A2 gives a mean SCCO2 of $72 per tonne.

Year in which the SCCO2 is calculated

In the PAGE2002 results reported in the Stern review, the extra tonne of CO2 is emitted in 2001. In the PAGE09 default model, the year in which the extra tonne is emitted is 2009. The PAGE2002 model does not have 2009 as an analysis year, but both models can produce results for 2010. Figure 6 shows the distribution of the SCCO2 for 2010 from PAGE2002, under the A1B scenario, and with all other inputs as for the Stern review. The mean value is $40 per tonne of CO2, up from $33 in 2001, with a 5 – 95% range of $8 – 106.

Figure 6 The SCCO2 in 2010 from the PAGE2002 model using Stern review inputs, A1B scenario



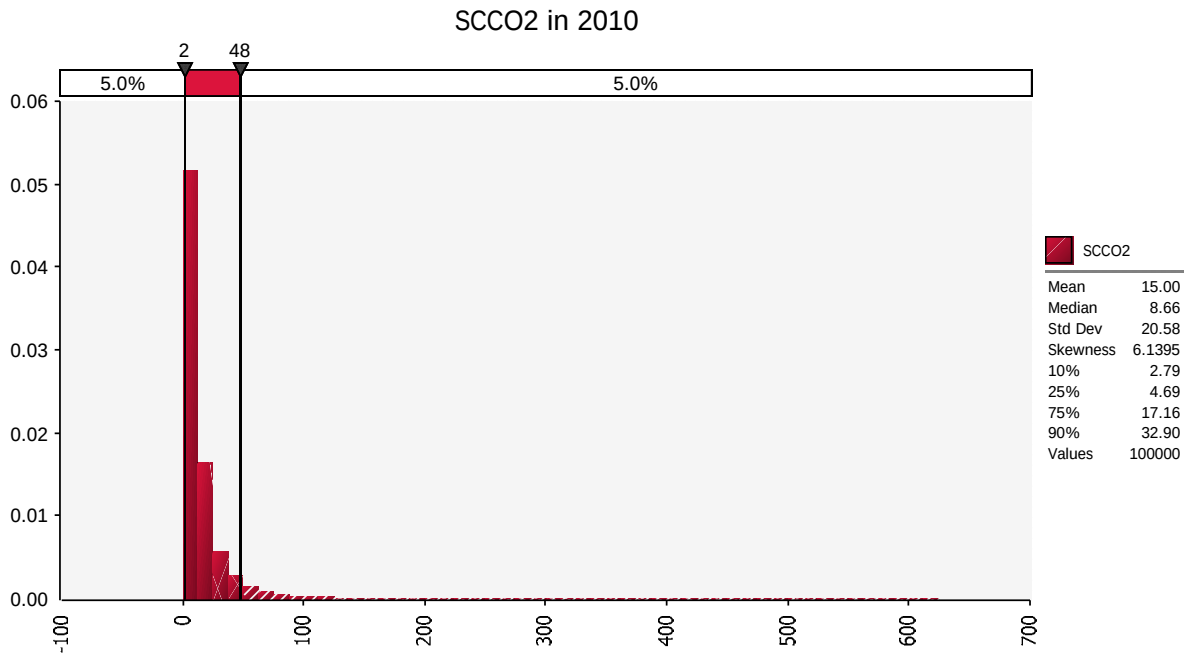
Discount rate and equity weights

The Stern review runs with PAGE2002 used single values of 0.1% per year for the pure time preference (PTP) rate and 1 for the elasticity of marginal utility of consumption (EMUC). The default PAGE09 model uses triangular distributions for these two parameters, as described in Hope, 2011b; the PTP values cover the range from the Stern review assumptions at the low end to the empirical

estimates in Nordhaus (2007) at the high end. The EMUC values are based on HM Treasury, 2003, which uses a value of 1.0, reduced from 1.5, and table 1 of Evans, 2005.

Figure 7 shows the SCCO2 produced by the PAGE2002 model for 2010 in the A1B scenario using the PAGE09 default triangular distributions for PTP and EMUC . Unsurprisingly, given the higher discount rate, the mean value drops to $15 per tonne of CO2, with a 5 – 95% range of $2 – 48.

Figure 7 The SCCO2 in 2010 from the PAGE2002 model using Stern review inputs, A1B scenario, PAGE09 values for PTP and EMUC.

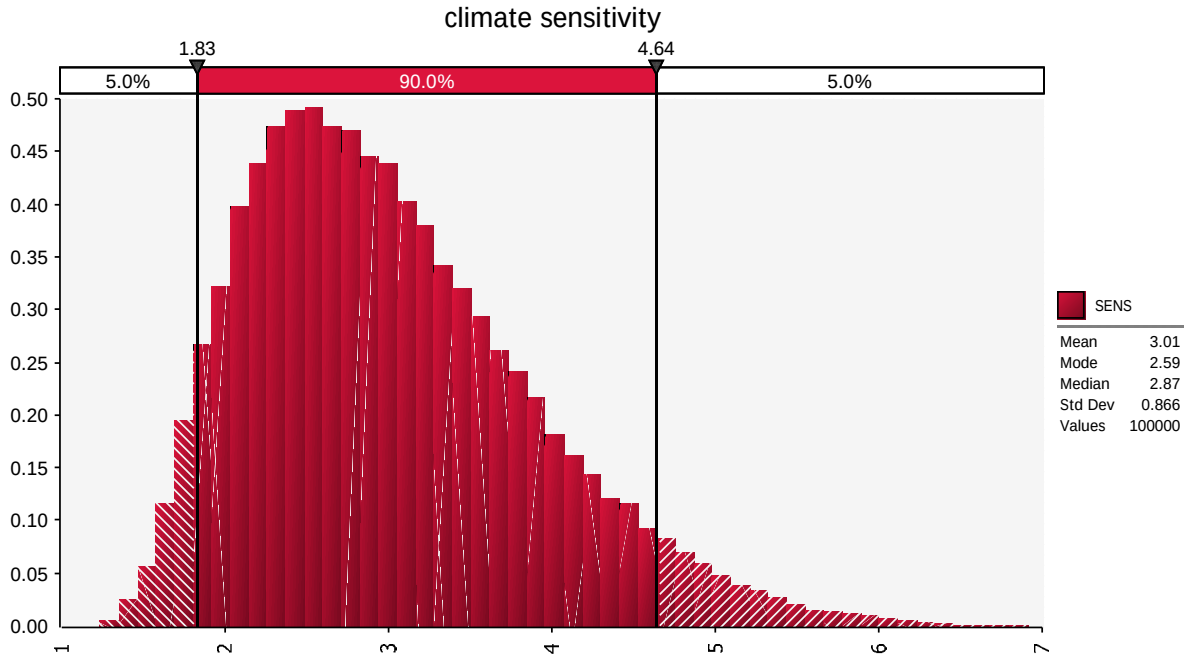


Converting this mean result to $2005, using the US GDP deflator (US Dept of Commerce, 2011), it comes to $17 per tonne of CO2. This is now a long way from the PAGE09 default mean value of $106 per tonne of CO2.

Climate sensitivity

How about the other two main influences identified in figure 4, the components of the climate sensitivity, TCR and FRT? The Stern review used triangular distributions for the climate sensitivity of <1.5,2.5,4.5> degC, giving a mean value of 2.83 degC, and for the FRT of <25,50,75> years, giving a mean value of 50 years. The FRT used in the default PAGE09 model is a triangular distribution of <10,30,65> years, giving a mean value of 35 years; the climate sensitivity distribution is shown in figure 8 (Hope, 2011b).

Figure 8 Climate sensitivity probability distribution in the default PAGE09 model.

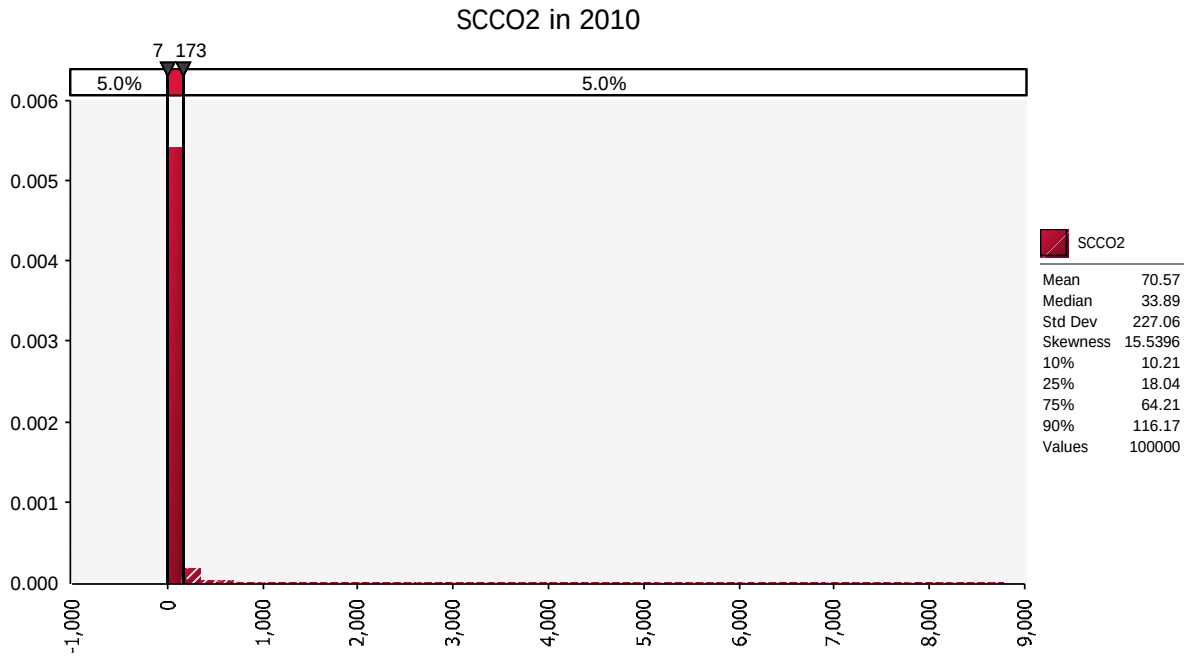


The lowest values are about 1.5 degC, there is a 5% chance that it will be below about 1.85 degC, the most likely value is about 2.6 degC, the mean value is about 3 degC, there is a 5% chance that it will be above 4.6 degC, and a long tail reaching out to nearly 7 degC. This distribution is consistent with the latest estimates from IPCC, 2007.

It is not possible to adjust the PAGE2002 input parameters to reproduce the form for the climate sensitivity used in PAGE09, so instead we work from the other end of the puzzle, and adjust the default PAGE09 model so that it uses the same input distributions for the climate sensitivity and FRT that were used in the Stern review.

Figure 9 shows that the mean SCCO2 drops from $106 to $71 per tonne of CO2, with a 5 – 95% range of $7 – 173. This is unsurprising as the mean climate sensitivity in the Stern review is lower and the mean FRT is longer than in the default PAGE09 model.

Figure 9 The SCCO2 from the PAGE09 default model, Stern climate sensitivity and FRT



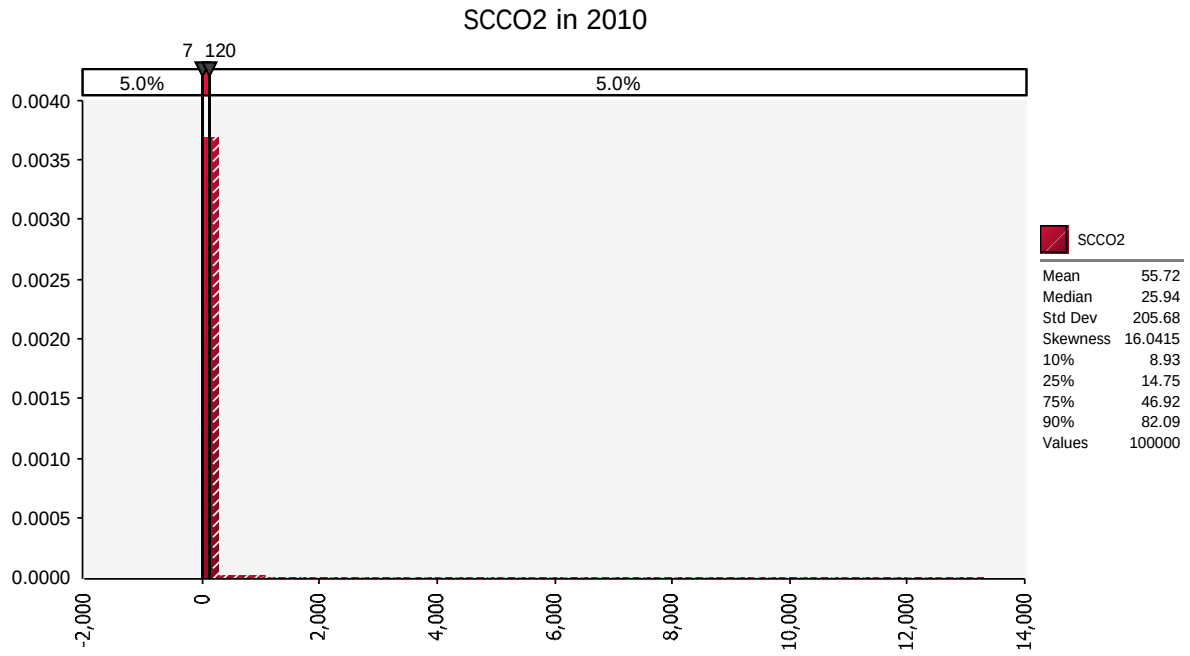
Adaptation

The adaptation inputs are policy variables in PAGE09, as they are in PAGE2002. They result from policy decisions and are represented as single choice values rather than probability distributions, and so they do not appear in the tornado diagrams of major influences. However, the decisions about adaption clearly can have a major influence of the SCCO2; in the extreme, if adaptation were to be 100% effective in every sector everywhere and for all time, the SCCO2 would be zero.

The default adaptation assumptions in PAGE09 (see Hope, 2011b for details) assume less adaptation than in the Stern review runs with PAGE2002, particularly in the economic sector, which was criticised for possibly being over-optimistic (Ackerman et al, 2009). Running the PAGE09 default model with the adaptation used in the Stern review reduces the mean SCCO2 from $106 to $83; running it with no adaptation gives a mean SCCO2 of $127. So the default adaptation assumptions in the PAGE09 model are in aggregate about half as effective as those assumed in the Stern review.

Running the default PAGE09 model with the Stern climate sensitivity and FRT, and the Stern adaptation, gives the SCCO2 distribution shown in figure 10. The mean SCCO2 drops further to $56 per tonne of CO2, with a 5 – 95% range of $7 – 120, but is still clearly a lot higher than the mean equivalent result from the PAGE2002 model of $17 per tonne of CO2.

Figure 10 The SCCO2 from the PAGE09 default model, Stern climate sensitivity, FRT and adaptation.



Basis of valuation

The main explanation for the remaining difference is the basis on which the economic values in the two models are expressed. In the PAGE2002 model, the equity weighting is applied in such a way that impacts are increased in regions whose GDP per capita is lower than the global mean, and vice versa. Implicitly, the SCCO2 that is calculated is the one appropriate to a representative agent with income equal to the global mean GDP per capita.

In the PAGE09 model, the equity weighting is applied in such a way that impacts are increased in regions whose GDP per capita is lower than the GDP per capita in the focus region of the model, which in the default model is the European Union (EU), and vice versa (Hope, 2011a). The SCCO2 that is calculated is the one appropriate to a representative agent with income equal to the mean GDP per capita in the EU in the year in which the SCCO2 is calculated.

In the PAGE2002 model used for the Stern review, the mean global GDP per capita in the base year, 2000, is $8063, in $2005. In the default PAGE09 model, the mean EU GDP per capita in 2010 is $28400, in $2005, 3.5 times as high. Applying the mean EMUC in the default PAGE09 model of 1.1667, the SCCO2 should be adjusted by a factor of 4.34 to correct for this difference.

There are two equivalent ways of making the adjustment. Either we can say that the mean SCCO2 from the PAGE09 model shown in figure 10 of $56 should be divided by 4.34 to apply to an agent with the mean global GDP per capita in 2000, which gives a mean value of $13 per tonne of CO2. Or we can say that the mean SCCO2 from the PAGE2002 model shown in figure 7, in $2005, of $17 should be multiplied by 4.34 to apply to an agent with the mean EU GDP per capita in 2008, which gives a mean value of $73 per tonne of CO2.

Whichever of the two methods we choose to use, we can say that the mean SCCO2 results from the Stern PAGE2002 and default PAGE09 models are within 25% of each other, provided we use inputs that are harmonized: the PAGE09 assumptions for the business as usual scenario, year of calculation, discount rates and equity weights, and the Stern assumptions for climate sensitivity, feedback response time and adaptation. The values from the PAGE09 model are the lower of the two.

Other investigations

It is reasonable to ask why the results are not even closer. The answer is that there are several structural changes in the PAGE09 model that are impossible to set back to something approximating the earlier PAGE2002 form.

In particular, the non-economic and discontinuity impacts, which were also identified as major influences in figure 4, are explicitly linked to regional GDP per capita in PAGE09, but not in PAGE2002. Table 1 shows the mean SCCO2 from the default PAGE09 model if the impacts from any of the four sectors are set to zero.

Table 1 Mean SCCO2 from the PAGE09 model, by impact sector omitted

A1B scenario		*2010*
	Mean SCCO2 $	Drop from default %
Default model	**106**	
No non-economic impacts	62	*42*
No economic impacts	80	*25*
No sea level impacts	100	*6*
No discontinuities	79	*25*

It might be thought that the four drops in table 1 should sum to 100%; however they do not sum exactly as there are small interactions between them. If there are no non-economic impacts, for instance, the valuation of the discontinuity impacts will be slightly higher, as there will be more consumption remaining to be affected by any discontinuity that does occur.

Table 1 confirms the impression from figure 4 that the non-economic impacts are most important, with the mean SCCO2 dropping by 45% if they are omitted, and that discontinuities are about as important as economic impact, even though they are very unlikely to be triggered for several decades. The sea level impacts are lower for a variety of reasons: sea level rises more slowly than temperature, adaptation can be very effective against the first metre or so of sea level rise, and, unlike impacts that depend on temperature, the impacts from sea level rise seem as though they will only rise less than linearly with the amount of sea level rise (Anthoff et al, 2006).

One other experiment worth reporting is the result from the PAGE09 default model using the Stern PTP value of 0.1% per year, and EMUC of 1. This gives a mean SCCO2 in 2010 of $291 per tonne of

CO2. This is rather higher than the $220 implied by the values in figure 4. The lesson from this is that the tornado influence diagrams in the model are useful but not completely accurate, particularly for values of the inputs at the extreme ends of the input distributions.

To complete the investigation of influences identified as major in figure 4, PAGE09 with PAGE2002 indirect sulphate inputs gives a mean SCCO2 of $106, exactly as in the default model, as the treatment of indirect sulphates has not changed between PAGE2002 and PAGE09.

Discussion and conclusions

The development of the mean SCCO2, from the value in the PAGE2002 model with Stern input assumptions, to the value in the default PAGE09 model, is summarised in table 2. In each row the final column shows the factor by which the mean SCCO2 changes incrementally from the previous row, either as a multiplication if the value increases, or a division if it decreases.

Table 2 Development of mean SCCO2, by adjustment

	Mean SCCO2 $	Factor
PAGE2002 Stern	**81**	
A1B scenario not A2	33	2.5
2010 not 2001	40	1.2
New PTP and EMUC	15	2.7
$2005 not $2000	17	1.1
EU valuation not global mean	73	4.3
PAGE09 model not PAGE2002	*56*	*1.3*
New adaptation	71	1.3
New TCR and FRT	**106**	1.5

So, in the second row, going from the Stern inputs, which used the A2 scenario, to the A1B scenario, divides the mean SCCO2 by a factor of 2.5. Keeping this change but also having the extra emissions in 2010 rather than 2001, multiplies the previous result by a factor of 1.2, and so on.

The table provides an easy way of recognising which incremental changes bring the largest changes in mean SCCO2. The largest incremental change comes from expressing the valuation in terms of an agent with the mean EU GDP per capita rather than the global average. Because the agent in the EU is richer, they would be willing to give up more dollars of consumption to avoid the extra global impact from one more tonne of CO2.

Table 3 Mean SCCO2 from the default PAGE09 model, by region

A1B scenario	*2010*
	Mean SCCO2 $ per tonne
EU	106

USA	166
Other OECD	101
FSU & ROE	33
China & CP Asia	15
India & SE Asia	10
Africa & ME	11
Latin America	32

This has implications when we think about the mean SCCO2 in other regions of the world. It will be higher in rich regions like the US, and lower in poor regions. Table 3 shows that the mean value varies from a low of $10 per tonne of CO2 in India, to a high of $166 in the USA. As long as inequalities persist in mean GDP per capita across world regions, it will be appropriate to use different values of SCCO2, and by implication, different taxes on the emissions of CO2, in different regions.

The two next largest factors in table 2 are also to do with economics rather than science. Using the full range of values for discount rates and equity weights, rather than the single values in the Stern review, reduces the mean SCCO2 by a factor of 2.7. And using the A1B scenario rather than the A2 scenario reduces the mean SCCO2 by a factor of 2.5, almost entirely because of the different socio-economics in the A1B scenario, not because of the different emissions.

The newer estimates of the transient climate response and feedback response time in the default PAGE09 model increase the mean SCCO2 by a factor of 1.5, and this is the most influential scientific update. All the remaining structural and parametric improvements of moving to the PAGE09 model, shown in italics in table 2, have a net effect of decreasing the mean SCCO2 by a factor of 1.3. The less effective adaptation assumed in the default PAGE09 model has the opposite effect, increasing the mean SCCO2 by a factor of 1.3.

Moving the extra emissions from 2001 to 2010 increase the mean SCCO2 by a factor 1.2, and expressing the result in $2005 rather than $2000 increases the mean SCCO2 by a factor of 1.1.

So these results suggest a set of five questions that users should ask when they are presented with an SCCO2 result from an integrated assessment model:

1) Who is making the valuation? An agent in the USA, the EU, or a poorer region of the world?
2) What discount rate and equity weight assumptions have been used?
3) What is the socio-economic scenario on which the valuation is based?
4) What are the assumptions about climate sensitivity, and feedback response time?
5) What adaptation has been assumed?

These questions should be asked along with two others that are already known to be important, and to affect the results obtained by about a factor of 2 (Hope,2011b):

6) What scenario of future emissions has been assumed?
7) How have the risks and uncertainties been incorporated?

The results presented in this paper are only a small subset of the outputs that the PAGE09 model produces. Comparing marginal abatement costs with the social cost of CO2 helps to guide the search

for economically efficient emission cutback paths. The effects of different types of discontinuity on the SCCO2; the contribution to the SCCO2 from the long right tails of the input distributions; the social costs of the emissions of non-CO2 greenhouse gases – all these and more can easily be investigated with the PAGE09 model. Anyone interested in working with PAGE09 is invited to contact the author to obtain a copy of the model.

Acknowledgements

Development of the PAGE09 model received funding from the European Community's Seventh Framework Programme, as part of the ClimateCost Project (Full Costs of Climate Change, Grant Agreement 212774) www/climatecost.eu and from the UK Department of Energy and Climate Change. An earlier version of this paper was presented at the EPA climate damages workshop in Washington DC in November 2010.

References

Ackerman F, Stanton EA, Hope C and Alberth S, 2009, Did the Stern Review underestimate US and global climate damages? Energy Policy, 37(7): 2717-2721.

ADB, 2009, The Economics of Climate Change in Southeast Asia: A Regional Review, Asian Development Bank, Philippines.

Anthoff D, Nicholls RJ, Tol RSJ and Vafeidis AT, 2006, Global and regional exposure to large rises in sea-level: a sensitivity analysis. Working Paper 96, Tyndall Centre for Climate Change Research, Norwich, UK.

Dietz S, Hope C, Stern N & Zenghelis D, 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.

Eliasch J, 2008, Climate Change: Financing Global Forests. Office of Climate Change, UK.

Evans DJ, 2005, The elasticity of marginal utility of consumption: estimates for 20 OECD countries, Fiscal Studies 26, pp. 197–224.

HM Treasury, 2003, Appraisal and Evaluation in Central Government, The Green Book, London:HMSO.

Hope C, 2011a, The PAGE09 integrated assessment model: A technical description, Judge Business School Working paper 4/2011, submitted to Climatic Change.
http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1104.pdf

Hope C, 2011b, The Social Cost of CO2 from the PAGE09 model, Judge Business School Working paper 5/2011, submitted to Economics.
http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1105.pdf

Hope C, 2008, Discount rates, equity weights and the social cost of carbon, Energy Economics, 30, 3, 1011-1019.

Hope C, 2006a, The marginal impact of CO2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern, Integrated Assessment, 6, 1, 19-56.

Hope C, 2006b, The social cost of carbon: what does it actually depend on?, Climate Policy, 6, 5, 566 - 572.

IPCC, 2007, Climate Change 2007. The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat Switzerland.

Lenton TM, Held H, Kriegler E, JHall JW, Lucht W, Rahmstorf S and Schellnhuber HJ, 2008, Tipping elements in the Earth's climate system, Proceedings of the National Academy of Sciences USA 105(6), 1786–1793.

Nakicenovic N and Swart R, 2000, "Special Report on Emissions Scenarios (SRES)". Cambridge University Press, Cambridge, UK

Nordhaus WD, 2007, A Review of the Stern Review on the Economics of Climate Change, Journal of Economic Literature, 45(3): 686–702.

Stern N, 2007, The Economics of Climate Change: The Stern Review. Cambridge and New York: Cambridge University Press.

Tol R.J, 2002, New estimates of the damage costs of climate change, Part II: dynamic estimates, Environ. Resour. Econ., 21, 135-160.

US Department of Commerce, 2011, Gross Domestic Product: Implicit Price Deflator, http://research.stlouisfed.org/fred2/data/GDPDEF.txt