

## Overall assessment

This paper is strongly recommended for publication, because it

(a) describes in detail how the new version of PAGE which was used in the Stern review has been updated. It is very important that the economic and policy community understand the underlying changes to the model that result in new policy relevant information, and also that it is shown that the new calibrations are consistent with the latest literature.

(b) describes a new and important result, the contribution of Annex 1 versus the Rest of the World to the social cost of carbon, in an analysis which takes account of the uncertainties in the representation of impacts modelling, and in particular, the uncertainties in the relative weighting factors assigned to impacts in different world regions. This is a highly policy relevant result.

*Thank you*

I recommend some modifications to improve the paper before publication. Importantly, the key results about the regional split of the SCC are given currently as mean values, and the author should extract also the ranges from the modelling results and show these in the paper and the abstract (see detailed comments).

*The regional results are given as percentages of the global total. It is possible to collect this percentage information for each run, and so build up a probability distribution of the percentages as requested by the reviewer. However, this would be inadvisable as the resulting distributions would have several undesirable characteristics, including the mean value of the percentages not being equal to the percentages of the mean value shown in the tables. In other words, it is possible to average percentages but it is almost never what you want to do, and the best advice is not to do it, ever.*

In particular, it should be made clear whether adaptation is or is not included in these figures, and whether this is an 'optimal' or some kind of maximum feasible level.

*The results include the default, moderate, amount of adaptation and this is described in table 8 and the accompanying text. It would be possible to note this further in the key results, such as figure 4.*

I would also like to see how the results vary with or without the inclusion of adaptation, which is much better represented in the new version of PAGE than it was in the previous version. This last addition is not essential for publication, but the paper would be much improved if this was included.

*Future papers will present a full analysis of how the results change with variations in many of the key assumptions, including adaptation.*

Slightly more detailed comments about how to make the modifications are given below. Finally, the large number of minor comments are matters of clarification and suggestions for improvements to wording as the reviewer would like to help the author communicate the work as clearly as possible.

**Detailed comments** (these largely describe the above recommendations in more detail)

Abstract: Since PAGE is a probabilistic model, give ranges as well as single values for the numbers that you quote in the abstract. It is important, because PAGE is doing a good job of reflecting its uncertainty in estimating how impacts vary across regions, but this is not reflected in the abstract.

*The ranges can and should be quoted for the global SCCO2 values, but not for the percentages, for the reason noted above.*

What are the assumptions about adaptation in these headline figures? If you can derive the figures with and without adaptation (See below) include them in the abstract.

*A phrase describing the adaptation assumptions could be added.*

'Sea level rise impacts rise less than linearly' where have the values of the exponent come from, or did you simply choose them to make the outcome match that of Warren et al 2006 once you had incorporated Ackerman's value for economic and non-economic impacts? If so that is reasonable.

*This comes from Anthoff et al, as referenced.*

Page 8: adaptation and deBruin. Discuss whether to model 'optimal' levels of adaptation or 'maximum feasible' levels of adaptation. Which did you choose here? What did deBruin base their optimisation upon? Balancing adaptation costs and damage costs? Or adaptation costs and mitigation costs, and is this a global study or EU study?

*It is a first attempt to model what optimal adaptation might look like. As noted, the evidence base is very thin here.*

I also find the phrase 'residual damages without adaptation' confusing. Residual damage is usually used to describe that which remains after mitigation, after adaptation, or after a combination of both - please clarify.

*This was poorly phrased. It should say 'residual damages of about 85% of **the** damages without adaptation', in other words adaptation reduces the damages by about 15%.*

The fact that adaptation is included as a choice in the model, as a variable value rather than just on/off, is very positive.

*Thank you.*

Page 11. The reader would like to see Figures 4 and 5 plotted with and without adaptation, so that we can perhaps assume, that reality might be somewhere between the two. Also it's important to know if the adaptation applied is the 'optimal' level calculated by DeBruin, or the maximum feasible adaptation (the maximum being defined by both physical and economic and social constraints).

*Variation in the results with other amounts of adaptation is the subject of a future paper.*

Are there any estimates of adaptation costs, since shouldn't these be added to the NPV of damages, and should they not contribute to the SCC? They are expenses that would not have been incurred without climate change.

*Adaptation costs (and mitigation costs) are included in the total effects of climate change, and will be described fully in future papers leading towards a probabilistic cost-benefit analysis of policy measures, but they are not the focus of this paper.*

If I am right on this point, then the values of SCC with adaptation should be stated to be conservative. This point could be discussed and mentioned as a candidate for future work, perhaps.

*Inclusion of adaptation costs would not affect the SCCO2 to a first approximation, since it is unlikely that adaptation measures would be changed just because emissions had increased or reduced by one tonne. So the adaptation costs are the same in both cases.*

Pp14-16 The reader would like to see the adaptation policy variable shown in Figure 7. Or, if only simulations were with adaptation 'on' and 'off', please show what Figures 6 and 7 are like with/without adaptation, currently you do not explain whether adaptation occurs in these Figures but presumably so as a default.

*A phrase describing the adaptation assumptions could be added.*

Page 17-18 Please give uncertainty ranges on the data shown here and match with summary findings in abstract. Only the mean results are quoted here. The min and max values in these tables would be very interesting to see.

*This is not recommended for the reason noted above*

Page 17-18 What would these tables look like in the absence of adaptation? Or supposing, there was adaptation in the Annex 1 and not in the RoW? These might be questions for future work but if you can easily include the results here, please do. At least in the abstract please explain whether the results assume adaptation or not and in Annex 1 or RoW.

*A phrase describing the adaptation assumptions could be added. Variation in the results with other amounts of adaptation is the subject of a future paper, and this could be mentioned under future work.*

Page 6: the assumption that only one discontinuity occurs seems over optimistic. You might want to add that this may be so and say that future work will explore the potential for multiple discontinuities.

*The discontinuity is more of an abstract category. If it occurs even once, the losses are very large indeed. It would be possible to mention that the 'bad' ends of the normal impact sectors also give large possible losses, which might be worth avoiding if possible.*

Should there be a conclusion?

*One could be added if desired, but it would largely repeat material already covered.*

## **Minor Comments**

### *On Abstract:*

Since the abstract should be readily understood standalone, here is how it can be misunderstood if one does not read the rest of the paper. Suggest make edits so it stands alone.

Abstract: Sentence 2: reword, since 'scientific' encompasses the other three (impact, emission, adaptation) Suggest say 'The factors which are most influential in determining the value of the SCC emerging from the latest default version of the model, PAGE09 v1.7, are described. These include the input emissions, adaptation assumptions, and the representation of climate change and its impacts'.

*Although scientific encompasses the other three in continental Europe, it does not in the English-speaking world. So I would prefer to leave this sentence as it is.*

What is meant by 'the scientific and economic impact results'? What results? Values of SCC? Or

something else? What scientific impact results? Suggests PAGE is outputting impacts in physical quantities, which I'm sure it's not.

*The sentence implies scientific results (eg the concentration and temperature results shown in figures 2 and 3), not scientific impact results. I feel this is clear enough, but if not I am happy to rephrase slightly.*

'Aims to' Rather, say that using a probabilistic climate model, xx, the scenario has a yy% probability of constraining annual global mean temp rise to below z C.

*The rather vague phrasing is because the scenario was designed to achieve this result, but does not quite do so when run through the PAGE09 model, which includes enhanced carbon cycle feedback. In the PAGE09 model the mean global mean temperature actually rises by 2.2 degC, as explained in the text accompanying figure 3 in the results section. I think this is probably too much information to give in the abstract, and the text as it stands does the task it is meant to, which is to demonstrate that the scenario is one of aggressive abatement, but I am happy to rephrase if required.*

'Today's mean social cost'. The reader can think you are talking about a measured amount in the real world. Reword to say, 'The model finds that the value of the SCC today is about \$100

*I am happy to make this change, as long as it says value of the SCCO2.*

Last part: 'impacts in annex 1 from annex 1 emissions' and 'impacts in RoW from RoW emissions'. I know what you have done mathematically, but this doesn't make sense stand alone because impacts can't be assigned to a particular emitting country – all the CO2 from everywhere causes all the impacts. Hence suggest reword as follows: If the damage in Annex 1 countries is apportioned according to the ratio of emissions in Annex 1 to those of the RoW, and similarly for the RoW emissions, then the Annex1 emissions' effect on impacts in Annex 1 countries contributes to less than 10% of the SCC value. In contrast, 45% of the SCC value comes from damages in RoW countries apportioned to RoW emissions. Just over 10% of the value arises from impacts in Annex 1 apportioned to emissions in the RoW.

*This rephrasing is more precise, but much more clumsy. I am happy to include it if required, but think the existing phrasing is better for the abstract, while the suggested rewording is better in the discussion around table 9.*

Question: presumably then, 35% of the SCC value is due to impacts in Annex 1 countries apportioned to emissions in the RoW. I think this is worth emphasizing in the abstract, as it is quite an interesting result too.

*It is actually 13% (see table 10). I am happy to mention this in the abstract.*

BAU scenario: in the abstract, say what the BAU scenario is.

*I am happy to do this.*

*On Introduction:*

Para 3: as above re 'scientific, impact, emission and adaptaton' suggest reword to match suggested reword in abstract.

*Same response as above.*

Para 5: economic and non-economic would seem to encompass everything. So need to reword as follows: 'impacts due to gradual changes in climate, in (i) economic sectors (ii) non-economic sectors, and also those arising from rapid changes in climate which may occur in response to feedback processes in the earth system (reference Lenton's paper ) which are termed 'discontinuities'. Impacts from sea level rise are treated in a separate category. However, presumably sea level rise then has both economic and non-economic impacts, but presumably this category includes both types of impacts then?

*This extra explanation is useful and I am happy to write something like it.*

Question: what about sea level rise impacts that are discontinuities, like melting of Greenland Ice Sheet? Which category are they in? Are they included?

*They are included in the discontinuities, so the text above should note that the sea level impacts are those from normal, gradual climate change.*

Page 3. Effects of sulphates.

'Not easily understandable' I'm not sure this matters. What matters is whether it was correct, and whether the new version is more accurate ...the overall numbers are unchanged since PAGE2005.

*In a model like PAGE which gives the user great freedom to adjust parameters, it is important that the parameters are easily understood. However I am happy to remove this phrase if required.*

Can you be clearer about the changes since PAGE 2005?

*These are explicitly stated at the bottom of page 3.*

Page 4. Carbon cycle feedback, para 2. 'Carbon cycle feedbacks with mean values in 2100 of about 95ppm' Not sure what the units of 'carbon cycle feedback are, as this is a process, but they might be ppm per ton C ... suggest reword to, 'the carbon cycle feedback thus simulated produces CO2 concentrations which are enhanced by approximately 95ppm by 2100 ...' etc. Edit rest of para 2 in like mind.

*The suggested changes are clearer and I will adopt them.*

You list Warren et al 2010 in the reference list, suggest that you explain that the changes to the representation of carbon cycle feedback addresses the issue raised about overestimated CO2 concentrations in the older version of PAGE that was noted in that paper.

*I say that 'PAGE09 is much better able to simulate these carbon cycle feedback results than PAGE2002.', but am happy to add more detail if required.*

*On impacts section*

Title 'sea level, economic and non-economic' is OK if wording is changed where the impact categories are explained on page 1. Next sentence may not be necessary here but if included change wording to match suggested change to page 1 wording or add see page 1.

*Agreed.*

Table 4 Add 'in the EU' to the Table caption.

*Agreed.*

'The same range as in Ackerman et al 2009' Please explain what exactly is quoted in this paper that you have matched for the calibration.

*I am happy to cite the specific table.*

Clarify if the Warren and Ackerman numbers refer to the EU only.

*Warren et al is relevant to the EU. The exponent does not vary across regions.*

After Table 5, it is absolutely key to explain that PAGE has the good feature of including ranges for the multiplicative weight factors and also is capturing the uncertainty in the relative level of impacts between different regions, by considering these weights as independent variables in the uncertainty analysis. Because the representation of impacts across regions is uncertain, any study which attempts to apportion SCC to different parts of the world, must sample across the uncertainty ranges of these weighting factors. PAGE does this, and it is very important to emphasize that this is the case, as it justifies the validity of the central result presented in the abstract.

*I am happy to add this extra detail in the text.*

It is also important therefore, to include more detail about how Anthoff et al (2006) arrive at these ranges for the weighting factors. Does Anthoff et al provide the ranges as well as the mean or mode?

*It does provide ranges, which I simulated to arrive at the multiplicative weight ranges. I can add this detail to the text.*

Page 6: how are impacts linked to GDP per capita? Is there an assumption that impacts decline with increasing GDP? If so what kind of relationship is assumed?

*In the default model, economic and discontinuity impacts decline with increasing GDP, but non-economic impacts do not. It would be possible to add this extra detail in the text here.*

Page 6: discontinuities. *When* does the EU lose 5-25% of its GDP?

*Once the full effect of the discontinuity is felt. This is explained later in the text: The losses build up gradually with a mean characteristic lifetime of 90 years, and a range of 20 -200 years, after the discontinuity is triggered.*

Page 8 Emissions. Mention that current emission trends are closer to an A1FI pathway, can you comment in the discussion then about whether the results might have higher or lower values of SCC in this case?

*I am happy to add a sentence about current emission trends here, and include the consequences in the discussion.*

Page 8. Adaptation, 'it only works ... (3 deg)' it's not clear here whether you mean 1+2=3 deg or whether you mean 3+2=5 deg . Please clarify.

*I can rephrase as : It only works for the first 2 degC of temperature rise above the tolerable level of 1 degC (all temperatures measured with reference to their pre-industrial values)*

Page 8. Last para, Parry et al 2009. At what global temp rise does Parry have adaptation as 80% effective in the agricultural sector? Does this include the possible confounding effects of pests and diseases and increases in tropospheric ozone concentrations that are generally not included in ag models? In which case might the Parry estimate be conservative?

*I am happy to add a phrase containing this information, and the observation that it may be optimistic.*

Page 8 Adaptation, please explain what you set the adaptation policy variable to in this study, eg 1 and 0 or other values.

*The values in table 8 refer to this study, which uses the default model. I can add a phrase to make this clear.*

Figure 5 should have a colour key indicating that red is BAU and purple is the low emissions scenario.

*This is the same colour key as used throughout, but I agree it should also be spelled out here.*

Page 15 discussion here is very good and clear.

*Thank you*

Page 8 Treatment of adaptation in non-economic sectors is good

*Thank you*