WORKING PAPER

Calculating the impact of climate change on economic growth

MARCH 2017

ACT
ACTION ON CLIMATE TODAY

ACT (Action on Climate Today) is an initiative funded with UK aid from the UK government and managed by Oxford Policy Management. ACT brings together two UK Department for International Development programmes: the Climate Proofing Growth and Development (CPGD) programme and the Climate Change Innovation Programme (CCIP). The views expressed in this leaflet do not necessarily reflect the UK government's official policies.

We would like to acknowledge the intellectual contributions of Vivid Economics to this publication.

The future economic impacts of climate change have been considered since the mid-1990s, but are still only partially understood. Estimates of the economic impacts of climate change vary significantly depending on the approach taken and on the underlying assumptions used. There are a number of possible approaches, including a range of different economic modelling approaches. All approaches face similar challenges around estimating future expected sensitivity of temperatures to greenhouse gas emissions and the link between temperature changes and economic damages.

There is also significant uncertainty in attempting to project future economic growth in the long term, even before considering the impacts of climate change. Economic modelling of this underlying growth relies on assumptions about levels and causes of economic growth. Nonetheless, recent analyses provide estimates that can support decision making, though these values should always be considered alongside the caveats around their reliability.

Conceptualising the economic implications of climate change

There are two types of physical impacts that can have economic impacts: persistent changes in the climate and greater climatic variability. Persistent changes include long-term changes in factors such as temperature, precipitation levels, and the frequency and intensity of extreme events. Greater climatic variability includes impacts such as increasing variability and unpredictability of annual or seasonal precipitation levels, or changes in the predictability of other weather patterns or extreme events. For example, South Asia could experience a declining trend in seasonal mean rainfall at the same time as increasing unpredictability about the levels of rainfall in any given year or season.

These physical impacts will affect economic performance through two transmission mechanisms. Both persistent changes in climate and increased variability of the climate will have:

- **Direct impacts on output;** for example, climate change could lead to increased droughts or floods, which will in turn lead to decreased agricultural production due to climate change induced losses.
- **Indirect impacts on drivers of growth;** for example, for a growth rate in the range of 1–8%, a reduction of 0.5% in the annual growth rate leads to overall levels of income that are 5% lower after 10 years, over 20% lower after 50 years, and almost 40% lower after 100 years.

The effect of climate change on a number of underlying drivers of growth could have a much more dramatic long-term effect, due to compounding impacts over time. Figure 1 illustrates the types of climate change impact that may affect levels of output and drivers of growth.

Figure 1. Examples of mechanisms through which climate change can impact output and drivers of growth

	OUTPUT	DRIVERS OF GROWTH
CLIMATIC VARIABILITY	Increasing variation in rainfall may lead to more frequent and less predictable droughts and floods, increasing losses from flood damage and agricultural losses	Increasing climatic variability may require additional investments in new infrastructure and in maintaining infrastructure, diverting capital away from its most productive use and towards reconstruction and climate-proofing infrastructure for future variability
PERSISTENT CHANGE	Increasing temperatures, changes to precipitation patterns or changes to other environmental factors (such as the Gulf Stream) may lead to increased damages; for example, changes in temperature could push the agriculture sector outside optimum growing conditions	Increasing temperatures may decrease firm productivity, lead to permanent loss of natural capital and reduce political stability

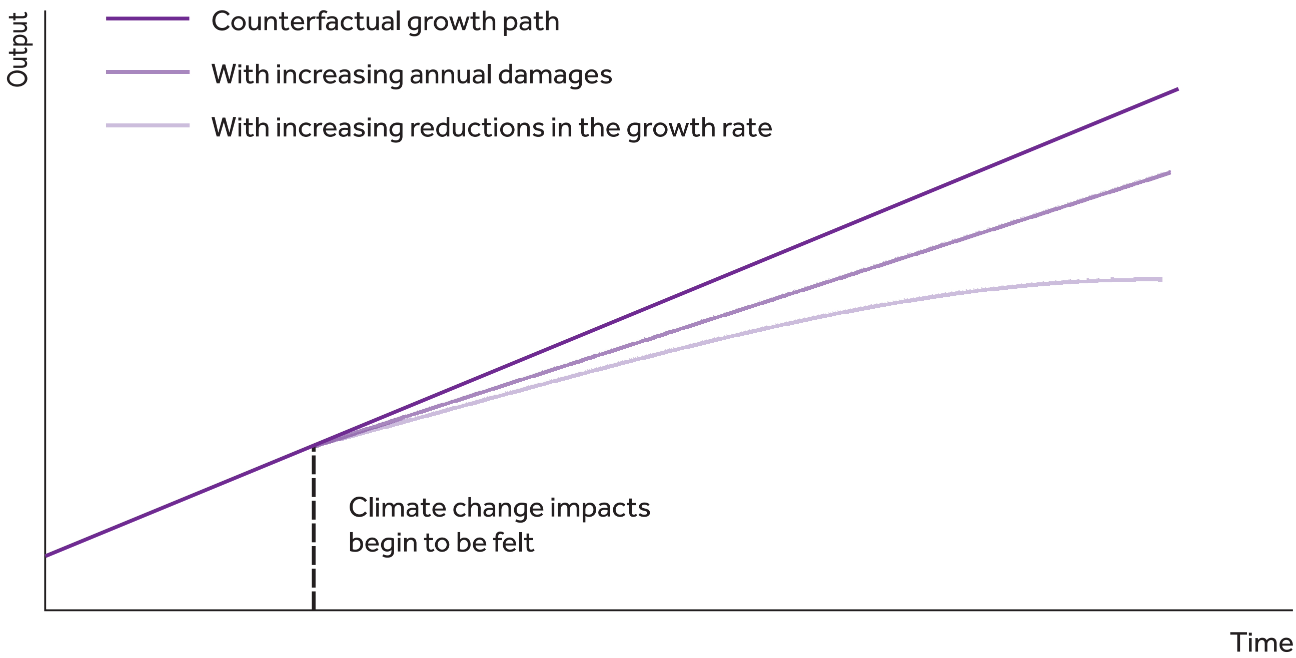
There are a number of additional ways in which climate change can impact economic growth:

- **Climate change may also affect how actors behave.** People may alter their behaviour in response to both persistent changes and increases in climatic variability. For example, increased temperatures may affect individuals' demand for energy for air conditioning and increased uncertainty around the future may affect households' plans, including their savings and consumption.
- **Extreme events and disasters can also affect how economies grow, beyond their immediate direct costs.** Extreme events can lead to significant direct losses of assets that have a market value, as well as losses of assets that do not have a market value (such as loss of life and damage to natural and cultural assets). However, they also include indirect losses, including the lost output resulting from reduced productive capital and the output that is lost as capital when it is redirected towards reconstruction of assets that were destroyed, away from more productive uses. In addition, other factors can affect economic costs such as price changes after a natural disaster that could, for example, increase indirect costs or reduce the costs of reconstruction (Hallegatte & Przyluski, 2010).
- **Extreme events can also lead to persistent reductions in output, where economies never recover sufficiently to reach their previous potential economic growth path (called 'hysteresis').** This can arise because, after a disaster, governments may shift expenditure towards capital spending for recovery; this may reduce investment in human capital, especially when governments do not have access to significant levels of foreign aid, which will reduce long run growth potential. Additionally, falls in wages or losses of capital may reduce employment and further depress wages.

This stylised relationship between climate change and economic activity can be expressed as a number of shifts away from a counterfactual growth path. Figure 2 illustrates stylised growth paths with and without climate change. The first panel shows a counterfactual growth path without climate change, the impact of increasing annual damages and the additional impact of increasing annual reductions to the growth rate.

Figure 2. Stylised graphical representation of the economic impacts of climate change

The figure depicts growth without climate change, decreased economic growth taking into account climate change damages and decreased growth rates as a result of impacts of climate change on growth generation potential/drivers of growth.



Calculating climate change impacts on Gross Domestic Product and growth rates

A range of approaches have been used to quantify the economic impacts of climate change. The key techniques used to model the impacts of climate change on Gross Domestic Product (GDP) and growth include two different approaches: (i) simulation modelling approaches and (ii) statistical analyses of the relationship between historical climate fluctuations and the economy. However, the inclusion of impacts on drivers of economic growth is still at an early stage and has not been explicitly carried out in most analyses.

The most commonly used modelling approaches are Integrated Assessment Models (IAMs) and Computable General Equilibrium (CGE) models. In addition, recent studies have explored new approaches to modelling the economic outcomes of climate change, including Agent Based Modelling (ABM) and Dynamic Stochastic General Equilibrium (DSGE) modelling.

These modelling approaches can provide useful economic estimations of climate change impacts, but they also have important weaknesses:

- **Reliance on disputed or uncertain underlying assumptions;** for example, the IAMs make certain assumptions about the damage costs associated with temperature increases, which have been criticised for being arbitrary (Pindyck, 2013).
- **Failure to include impacts on GDP growth;** most models only provide estimates of damages on output without considering how climate change affects growth rates, such as through damages to social, organisation or environmental capital, among others (Stern, 2013). They are therefore likely to underestimate the impacts of climate change.
- **Assessment of total costs rather than impacts on GDP per se;** IAMs provide assessments of the welfare cost of climate change expressed as a proportion of GDP, rather than measuring the effect of climate change on GDP itself. For example, IAMs would in principle consider the costs of recovery after an extreme weather event to be a cost, even though GDP might be increased by reconstruction activities.

The second technique frequently used is statistical analysis of the economic impacts of past climatic fluctuations. These analyses tend to either look at specific extreme weather events, or fluctuations in annual temperature. This research typically explores how changes in temperature, along with other variables such as precipitation and windstorms, affect outcomes including economic growth, agricultural output, industrial output, labour productivity, energy demand, conflict and health (Dell, Jones, & Olken, 2014). Statistical analysis techniques also have important weaknesses:

- **Reliance on historical data;** the analyses are strongly grounded in empirical data. However, many studies are limited in scope.
- **Focus on the impact of a certain fluctuation in temperature relative to the mean;** this may be different in impact from the same increase in mean temperature as people may be able to adapt more effectively to long-term increases in mean temperature.
- **The links between climate and economy in the future may be fundamentally different to those that have prevailed in the recent past;** an economy's response to a 1°C increase in temperature above the historical mean may be different to its response to a similar 1°C increase from 3–4°C above the historical mean.

Results from global and regional studies of the economic impacts of climate change

Table 1 summarises the results and approaches used of some recent attempts to estimate the economic cost of climate change.

Table 1. Summary of global and regional studies of the economic impacts of climate change

STUDY NAME	KEY FINDINGS	APPROACH USED	LIMITATIONS OF APPROACH
The Stern Review on the Economics of Climate Change (Stern, 2007)	Climate change impacts could be equivalent to a 5.3% reduction in GDP per capita by 2200. However, these estimates of damages vary depending on what types of damages are included and whether a 'normal' or 'high' level of climate change is assumed.	IAM analysis using the PAGE model (PAGE2002); used the supporting literature provided in the IPCC's Third Assessment Report (IPCC, 2001).	Assumed a growth path that is independent of the level of, or response to, climate change. It did not focus on how climate change may influence economic growth rates.
The Economic Effects of Climate Change (Tol, 2009, 2014)	Temperature increases in the range of 2.5°C–3°C are likely to lead to damages equivalent to 0%–4.8% of GDP.	Reviewed eighteen studies including results from IAMs and CGE modelling.	Significant variation in studies reviewed, with some showing overall benefits and others showing much higher costs. Also significant regional variation in results.
IPCC's 2013 Fifth Assessment Report (AR5) (IPCC, 2014)	Additional temperature increases of around 2°C are likely to lead to losses equivalent to 0.2%–2% of GDP.	Reviewed multiple analyses of economic costs of climate change.	Did not provide any firm quantitative conclusions from the analysis that explored the impact of climate change on the rate of growth.
Endogenous growth, convexity of damage and climate risk (Dietz and Stern, 2015)	By 2200, per capita consumption could be 11%–24% lower than traditional modelling suggests, due to incorporating climate impacts on drivers of growth. Models that also incorporate changes to the damage function show even greater reductions, with per capita consumption being at least 50% lower than under traditional modelling.	Improved on approaches to estimating dynamic effects and climate changes damages to drivers of growth in IAMs.	Only explored a subset of potential avenues by which climate change may affect the rate of growth and presented the results for the impacts on different drivers of growth separately.

Table 1. Summary of global and regional studies of the economic impacts of climate change *Continued...*

STUDY NAME	KEY FINDINGS	APPROACH USED	LIMITATIONS OF APPROACH
The Economic Consequences of Climate Change (OECD, 2015)	Global damages could equal 2% of GDP in 2060, within a range of around 1%–3%. A projected 3.7% reduction in annual GDP by 2060 in South and South East Asia, and 4.3% for India.	CGE modelling approach, which enabled it to explore sectoral impacts of climate change.	Relied on the internal assumptions and relationships between climate change and damages.
Global non-linear effect of temperature on economic production (Burke, Hsiang & Miguel, 2015)	Climate change could reduce average global GDP per capita by 23% by 2100, with reductions concentrated in poor countries.	Statistical analysis used a historic data set of national temperatures and economic outcomes.	Assumed that future adaptation to temperature increases would mimic historic adaptation.
IPCC's 'SREX' Report (IPCC, 2012)	During the period 2001–2006, losses from disasters amounted to 1% of total GDP in middle income countries and 0.3% of GDP in low income countries.	Estimated the size of impacts of extreme events on income and growth.	Difficult to extrapolate the future potential effects of extreme events on future GDP from such studies, as they represent only one component of climate change impacts.
Assessing the Costs of Climate Change and Adaptation in South Asia (Ahmed and Suphachalasai, 2014).	Bangladesh, India and Nepal could all experience annual damages equivalent to roughly 2% of GDP in 2050.	Analysis from an IAM.	Results are likely lower bounds given that the model used excluded some categories or impacts. Referred to damages as a proportion of GDP, rather than explicitly referring to impacts on GDP.

Research within ACT geographies

National or regional impacts of climate change can differ substantially from high-level estimates. Studies that disaggregate global estimates into regional or national impacts commonly find that costs are expected to be higher among lower income countries or in certain regions. Dell, Jones, & Olken (2014) and Burke, Hsiang, & Miguel (2015) suggest that the impact of climate change is likely to be greater in poor countries. The latter study also finds that South Asia is particularly at risk of large climate change damages. The OECD's modelling results also suggest significant damages, which are greater than the global average, are likely to accrue in ACT countries, as shown in Table 2. The OECD's results, which present both impacts on GDP and damages as a proportion of GDP for the overall region and for selected sub-regional groupings of countries, also show that impacts on GDP are expected to be marginally smaller than the total impacts in the South Asia region. The total costs represent 4.4% of GDP in India, 0.1% larger than the projected impact on GDP, while total costs are projected to be only 0.03% larger than GDP impacts in 'Other Asia'.

Table 2. Projected reduction in annual GDP due to climate change in 2060 in South Asia

GEOGRAPHY	CENTRAL ESTIMATE	LIKELY RANGE
South and South East Asia	3.7%	1.7%–4.9%
– India	4.3%	1.9%–8.4%
– Other Asia	3.2%	1.6%–4.8%
– Indonesia	2.3%	1.1%–3.7%
– Other ASEAN	2.7%	1.4%–3.7%

Note: OECD data are available for the aggregate 'South and South East Asia' region, and within this for India, Indonesia, 'Other ASEAN' and 'Other Asia', where 'Other Asia' excludes China.

Source: OECD (2015)

Analyses have also explored expected damages in South Asia specifically. Ahmed & Suphachalasai (2014) report analysis from an IAM for Bangladesh, India, Nepal, Bhutan, the Maldives and Sri Lanka. Their modelling suggests that Bangladesh, India and Nepal could all experience annual damages equivalent to roughly 2% of GDP in 2050 (2%, 1.8% and 2.2%, respectively). Although, the authors note that these are likely lower bounds, given that the model used excludes some categories or impacts. Aggregate modelling for the whole group of countries suggests that costs could increase significantly to around 8% by 2100. These levels are similar to modelled damages for other countries in the region. The Asian Development Bank has estimated damages for South East Asia using an IAM approach, suggesting that the region could experience annual losses of 2.2% of GDP by 2100, rising to 5.7%–6.7% if non-market impacts and catastrophic risks are included (Asian Development Bank, 2009). Similar analysis for East Asia also suggested that the region could experience losses amounting to 5.3% of GDP per annum by 2100. However, all estimates of impacts presented refer to damages as a proportion of GDP, rather than explicitly referring to impacts on GDP.

Recommendations for understanding and using estimates of economic impacts of climate change

Results from the analyses presented above provide the best available evidence on the likely impacts of climate change on economic growth. However, it is important to use caution when basing analyses on estimates of economic impacts taken from modelling or other studies. The following are suggestions for how to understand and use the results:

- **Take care when using and comparing economic cost estimates, to ensure that values used align with their needs.** Studies present impacts in different ways: as annual deviations from a baseline growth path; as cumulative deviations from a baseline growth path; or as variations in growth paths themselves. Growth paths and damages may also be presented in aggregate or in per capita terms.
- **Over the medium-term future to 2050, it may be appropriate to base analysis on evidence from studies that do not explicitly include the impacts of climate change on the drivers of growth.** However, in the longer term, beyond 2050, more attention should be paid to the compounding effect of climate change on drivers of growth.
- **Medium-term increases in the scale of impacts are likely to be approximately linear.** When interpolating between the current date and 2050 (using a value from traditional economic modelling that excludes impacts on growth rates), a linear increase in the projected annual economic damages will approximate the expected real trend over this period of time. However, this approach would not be appropriate in the longer term, as the scale of economic damages is expected to increase exponentially over time.
- **In the short term, estimates based on statistical analyses of historical trends may provide more accurate estimates of damages.** However, looking further into the future, estimates based on historical responses are less likely to represent the economic costs of climate change as future climatic change and responses to it become less certain.

- **Recent economic modelling suggests that annual economic damages in South Asian countries are likely to fall within the range of 1%–5% of GDP in 2050.** Economic modelling for specific countries suggests that costs around 2% may be the most likely, though these do fall within a range of around 1%–5%.
- **These estimates are based on imperfect economic modelling and should be continually re-assessed as new evidence is identified.** New developments in economic modelling, especially those including modifications to directly include impacts on drivers of growth, will improve outputs from economic modelling in the future, such that they more accurately represent the full range of likely impacts of climate change.

References

Ahmed, M., & Suphachalasai, S. (2014). *Assessing the Costs of Climate Change and Adaptation in South Asia*. Retrieved from http://www.adb.org/sites/default/files/pub/2014/assessing-costs-climate-change-and-adaptation-south-asia.pdf

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature, 527*, 235–250. http://doi.org/10.1038/nature15725

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature, 52*(3), 740–798. http://doi.org/10.3386/w19578

Dietz, S., & Stern, N. (2015). Endogenous growth, convexity of damage and climate risk: How Nordhaus' framework supports deep cuts in carbon emissions. *Economic Journal, 125*(583), 574–620. http://doi.org/10.1111/ecoj.12188

Hallegatte, S., & Przyluski, V. (2010). *The Economics of Natural Disasters: Concepts and Methods* (No. 5507). *World Bank Policy Research Working Paper*. Washington D.C. http://doi.org/10.1146/annurev-resource-073009-104211

IPCC (2001). *Climate Change 2001, IPCC Third Assessment Report.*

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, & Q. Dahe, Eds.). Cambridge: Cambridge University Press. http://doi.org/10.1017/CBO9781139177245

IPCC (2014). *Climate Change 2014: Impacts, Adaptation and Vulnerability (Fifth Assessment Report of Working Group II of the Intergovernmental Panel on Climate Change).* Geneva.

OECD (2015). *The Economic Consequences of Climate Change.* Paris: OECD Publishing. http://doi.org/http://dx.doi.org/10.1787/9789264235410-en

Pindyck, R. S. (2013). Climate change policy: What do the models tell us? *Journal of Economic Literature, 51*(3), 860–872.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge: Cambridge University Press.

Stern, N. (2013). The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *Journal of Economic Literature, 51*(3), 838–859. http://doi.org/10.1257/jel.51.3.838

Tol, R. S. J. (2009). The economic effects of climate change. *The Journal of Economic Perspectives, 23*(2), 29–51. http://doi.org/10.1257/jep.23.2.29

Tol, R. S. J. (2014). Correction and update: The economic effects of climate change. *The Journal of Economic Perspectives, 28*(2), 221–226.

Appendix: Summary of Dietz & Stern, 2015: Endogenous growth, convexity of damage and climate risk

Dietz and Stern (2015) illustrate that adjusting models to both include climate impacts on drivers of growth and treat the relationship between rising temperatures and global damages differently can lead to much greater climate change damage estimates than under traditional modelling approaches.

Dietz and Stern's approach relaxes restrictions on traditional modelling that have likely led models to underestimate the costs of climate change. In 'Endogenous growth, convexity of damage and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions', Dietz and Stern amend the modelling framework of the Dynamic Integrated Climate–Economy (DICE) model, the pre-eminent IAM used in climate modelling, to take into account three elements of climate–economy interactions not typically included in DICE:

1. The *endogeneity of growth*, where long-run growth is not driven by assumed increases in productivity, but instead by underlying capital levels and knowledge spillovers to the overall economy from firms' capital investments and where climate change can damage these drivers of growth.
2. The *convex shape of the damage function*, where there is assumed to be a tipping point at some high temperature, beyond which damages increase significantly.
3. The *risk of higher temperatures for a given level of emissions*, where the probability of different temperatures for a given level of emissions is adjusted to match the latest knowledge on climate sensitivity to emissions and to explore the effects of high sensitivity under high emissions.

The authors' approach enables them to explore the specific impacts of changing these particular parameters. These amendments to the DICE modelling approach are intended to address limitations that have likely led such models to underestimate the costs of unabated climate change in previous modelling efforts (Stern, 2013). The approach is otherwise in line with the standard DICE modelling framework, which notably uses the standard – and arguably too high – discount rate to consider future costs and benefits; this allows for a comparison of the impacts of the authors' three changes compared to standard modelling approaches.

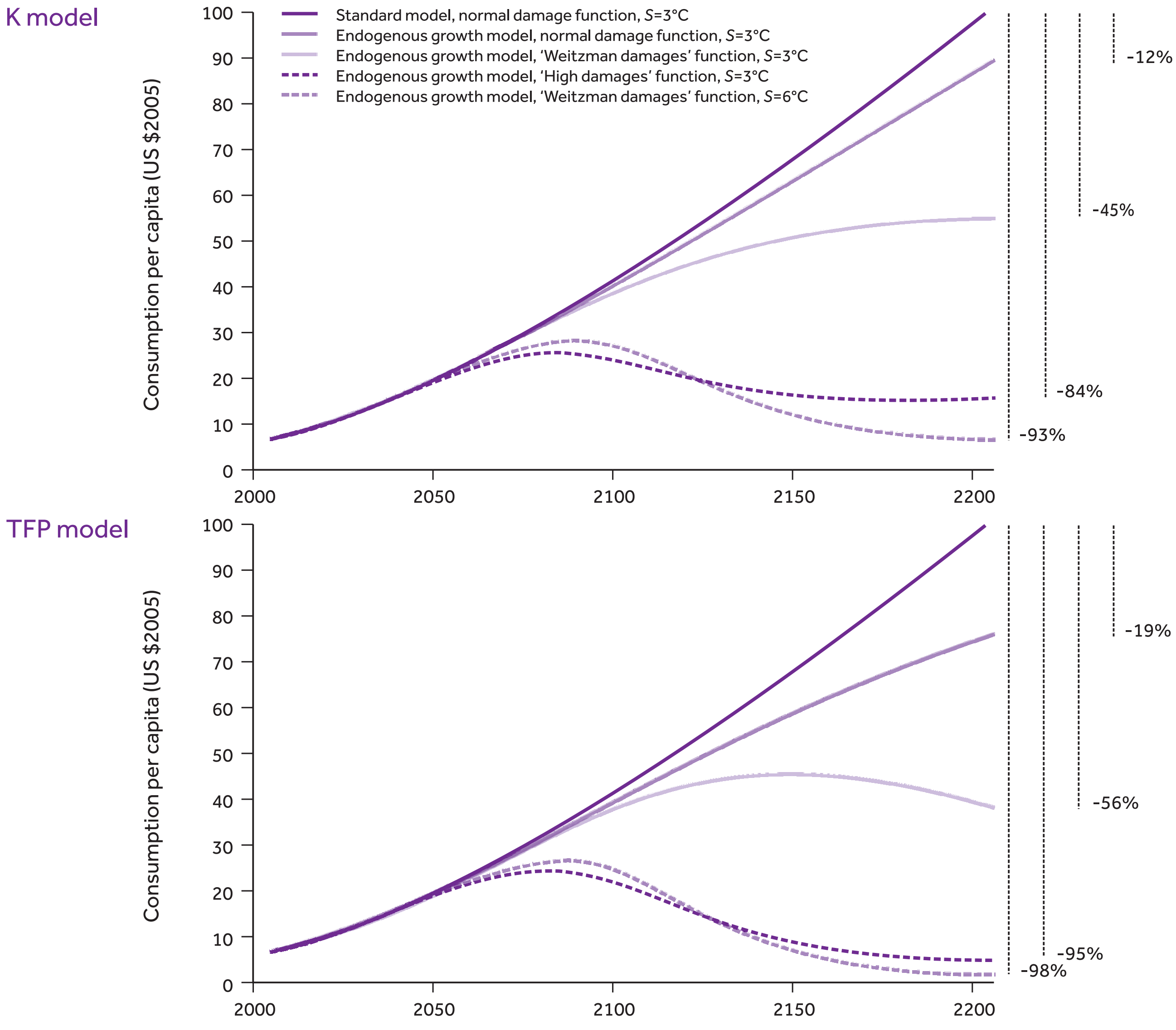
Dietz and Stern incorporate damages to drivers of growth through two modelling approaches. The first amendment to incorporate endogenous drivers of growth includes *knowledge spillovers and capital damage*, which modify the normal production function for economic output so that: (i) there are positive spillovers from the capital stock to the overall economy's productivity, representing the sharing of knowledge and learning-by-doing in the economy; and (ii) climate change damages the capital stock and hence also the knowledge spillover driver of growth, and not just the overall economic output as in standard modelling. The model assumes 30% of overall damages for a given temperature level accrue to the capital stock. The second *endogenous total* *factor productivity* approach uses a different model of productivity growth, where total factor productivity increases based on knowledge spillovers from capital investment only, rather than from the overall capital stock. This second model does not include direct damages to the capital stock, but does include damages to overall total factor productivity, where 5% of overall damages for a given temperature level accrue to total factor productivity, representing combined damages to the drivers of growth in the economy.

The changes to the shape of the damage function and the sensitivity of temperature to greenhouse gas emissions allow for higher damages at high temperatures and for an exploration of how damages change if temperature is more or less sensitive to emissions. The authors adjust the traditional damage function used in the DICE model to modify the function's reaction to high temperatures; this is because the damage function has been criticised for assuming relatively low damages even at high temperatures. The traditional damage function is quadratic, meaning that damages increase exponentially after some point, whereas the modified function includes an additional term that increases the scale of damages at high temperatures, following the approach used by Weitzman (2012). The authors include two variants, where the function is calibrated so that damages reach 50% of output when the temperature reaches either 6°C or 4°C. The use of the 6°C calibration reflects Weitzman's original calibration, whereas the 4°C calibration is based on recent evidence about the potential scale for high damages from climate change under a global average temperature increase of 4°C. To explore the possibility of differing levels of climate sensitivity, the authors adjust the sensitivity '*S*' parameter to allow for higher and lower levels of sensitivity. *S* represents the equilibrium change in global average surface temperature associated with a doubling of greenhouse gas emissions and is commonly set at 3°C in the standard DICE modelling framework. The authors conduct sensitivity analysis for high and low values of *S* based on a range of values derived from expert opinion by the IPCC (2013), using a low value of 1.5°C (where there is at most a 5% chance that *S* is below this value) and a high value of 6°C (where there is at most a 10% chance that *S* is above this value).

The results from the changes to the model suggest that climate change's impacts on drivers of growth could have significant impacts on future output and that amendments to damage functions could be even more significant. Figure A1 shows that, under both the capital stock-based knowledge spillover model (K model) and the endogenous total factor productivity model (TFP model), consumption will be reduced in models that incorporate drivers of growth and climate change damages to these drivers. The additional losses from the introduction of drivers to growth, but not any changes to the damage function, are relatively small in the near to medium term, but become increasingly significant after 2100. The differences increase in models that incorporate the modified damage function to include 'Weitzman damages' (50% losses at 6°C) or 'high damages' (50% losses at 4°C). Additionally, Figure A1 shows the result of a sensitivity analysis for setting the '*S*' parameter equal to 6°C and incorporating the 'Weitzman damages' function: higher sensitivity leads to much greater damages under both the endogenous growth models than under standard modelling, with the result that consumption in 2205 could be at similar levels to or lower than consumption in 2005.

Dietz and Stern argue that the scale of climate change damages justifies strong policy controls and a high price on carbon. In contrast with some modelling results, notably William Nordhaus' initial modelling using DICE, the results from this analysis suggest that the optimum response would be to implement a high carbon price now, which increases rapidly in real terms. The authors suggest the optimal price of carbon under a globally coordinated scheme would be in the range of USD 32 per tonne of CO_2 to USD 103 per tonne of CO_2 in 2015 (in 2012 prices), rising to USD 82 per tonne of CO_2 to USD 260 per tonne of CO_2 in real terms within two decades.

Figure A1. Changes to standard modelling assumptions do not significantly affect the level of climate change damages to 2050, but lead to significant increases in the long run



Source: Dietz & Stern (2015)

E: info@actiononclimate.today

W: actiononclimate.today

www.facebook.com/ActionOnClimate

@act_climate

ACT
ACTION ON CLIMATE TODAY

Oxford Policy Management

Supported by UKaid from the British people