

The damages from climate change will accelerate as the world gets warmer.

Higher temperatures will increase the chance of triggering abrupt and large-scale changes.

- Warming may induce sudden shifts in regional weather patterns such as the monsoon rains in South Asia or the El Niño phenomenon - changes that would have severe consequences for water availability and flooding in tropical regions and threaten the livelihoods of millions of people.
- A number of studies suggest that the Amazon rainforest could be vulnerable to climate change, with models projecting significant drying in this region. One model, for example, finds that the Amazon rainforest could be significantly, and possibly irrevocably, damaged by a warming of 2 - 3°C.
- The melting or collapse of ice sheets would eventually threaten land which today is home to 1 in every 20 people.

While there is much to learn about these risks, the temperatures that may result from unabated climate change will take the world outside the range of human experience. This points to the possibility of very damaging consequences.

The impacts of climate change are not evenly distributed - the poorest countries and people will suffer earliest and most. And if and when the damages appear it will be too late to reverse the process. Thus we are forced to look a long way ahead.

Climate change is a grave threat to the developing world and a major obstacle to continued poverty reduction across its many dimensions. First, developing regions are at a geographic disadvantage: they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries high costs and few benefits. Second, developing countries - in particular the poorest - are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and suffer from inadequate health provision and low-quality public services. Third, their low incomes and vulnerabilities make adaptation to climate change particularly difficult.

Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future, forcing them to use up meagre savings just to survive. At a national level, climate change will cut revenues and raise spending needs, worsening public finances.

Many developing countries are already struggling to cope with their current climate. Climatic shocks cause setbacks to economic and social development in developing countries today even with temperature increases of less than 1°C. The impacts of unabated climate change, - that is, increases of 3 or 4°C and upwards - will be to increase the risks and costs of these events very powerfully.

Impacts on this scale could spill over national borders, exacerbating the damage further. Rising sea levels and other climate-driven changes could drive millions of people to migrate: more than a fifth of Bangladesh could be under water with a 1m rise in sea levels, which is a possibility by the end of the century. Climate-related

shocks have sparked violent conflict in the past, and conflict is a serious risk in areas such as West Africa, the Nile Basin and Central Asia.

Climate change may initially have small positive effects for a few developed countries, but is likely to be very damaging for the much higher temperature increases expected by mid- to late-century under BAU scenarios.

In higher latitude regions, such as Canada, Russia and Scandinavia, climate change may lead to net benefits for temperature increases of 2 or 3°C, through higher agricultural yields, lower winter mortality, lower heating requirements, and a possible boost to tourism. But these regions will also experience the most rapid rates of warming, damaging infrastructure, human health, local livelihoods and biodiversity.

Developed countries in lower latitudes will be more vulnerable - for example, water availability and crop yields in southern Europe are expected to decline by 20% with a 2°C increase in global temperatures. Regions where water is already scarce will face serious difficulties and growing costs.

The increased costs of damage from extreme weather (storms, hurricanes, typhoons, floods, droughts, and heat waves) counteract some early benefits of climate change and will increase rapidly at higher temperatures. Based on simple extrapolations, costs of extreme weather alone could reach 0.5 - 1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm.

- A 5 or 10% increase in hurricane wind speed, linked to rising sea temperatures, is predicted approximately to double annual damage costs, in the USA.
- In the UK, annual flood losses alone could increase from 0.1% of GDP today to 0.2 - 0.4% of GDP once the increase in global average temperatures reaches 3 or 4°C.
- Heat waves like that experienced in 2003 in Europe, when 35,000 people died and agricultural losses reached \$15 billion, will be commonplace by the middle of the century.

At higher temperatures, developed economies face a growing risk of large-scale shocks - for example, the rising costs of extreme weather events could affect global financial markets through higher and more volatile costs of insurance.

Integrated assessment models provide a tool for estimating the total impact on the economy; our estimates suggest that this is likely to be higher than previously suggested.

The second approach to examining the risks and costs of climate change adopted in the Review is to use integrated assessment models to provide aggregate monetary estimates.

Formal modelling of the overall impact of climate change in monetary terms is a formidable challenge, and the limitations to modelling the world over two centuries or more demand great caution in interpreting results. However, as we have explained, the lags from action to effect are very long and the quantitative analysis needed to inform action will depend on such long-range modelling exercises. The monetary impacts of climate change are now expected to be more serious than many earlier studies suggested, not least because those studies tended to exclude some of the

most uncertain but potentially most damaging impacts. Thanks to recent advances in the science, it is now possible to examine these risks more directly, using probabilities.

Most formal modelling in the past has used as a starting point a scenario of 2-3°C warming. In this temperature range, the cost of climate change could be equivalent to a permanent loss of around 0-3% in global world output compared with what could have been achieved in a world without climate change. Developing countries will suffer even higher costs.

However, those earlier models were too optimistic about warming: more recent evidence indicates that temperature changes resulting from BAU trends in emissions may exceed 2-3°C by the end of this century. This increases the likelihood of a wider range of impacts than previously considered. Many of these impacts, such as abrupt and large-scale climate change, are more difficult to quantify. With 5-6°C warming - which is a real possibility for the next century - existing models that include the risk of abrupt and large-scale climate change estimate an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10% of GDP. Further, there is some evidence of small but significant risks of temperature rises even above this range. Such temperature increases would take us into territory unknown to human experience and involve radical changes in the world around us.

With such possibilities on the horizon, it was clear that the modelling framework used by this Review had to be built around the economics of risk. Averaging across possibilities conceals risks. The risks of outcomes much worse than expected are very real and they could be catastrophic. Policy on climate change is in large measure about reducing these risks. They cannot be fully eliminated, but they can be substantially reduced. Such a modelling framework has to take into account ethical judgements on the distribution of income and on how to treat future generations.

The analysis should not focus only on narrow measures of income like GDP. The consequences of climate change for health and for the environment are likely to be severe. Overall comparison of different strategies will include evaluation of these consequences too. Again, difficult conceptual, ethical and measurement issues are involved, and the results have to be treated with due circumspection.

The Review uses the results from one particular model, PAGE2002, to illustrate how the estimates derived from these integrated assessment models change in response to updated scientific evidence on the probabilities attached to degrees of temperature rise. The choice of model was guided by our desire to analyse risks explicitly - this is one of the very few models that would allow that exercise. Further, its underlying assumptions span the range of previous studies. We have used this model with one set of data consistent with the climate predictions of the 2001 report of the Intergovernmental Panel on Climate Change, and with one set that includes a small increase in the amplifying feedbacks in the climate system. This increase illustrates one area of the increased risks of climate change that have appeared in the peer-reviewed scientific literature published since 2001.

We have also considered how the application of appropriate discount rates, assumptions about the equity weighting attached to the valuation of impacts in poor countries, and estimates of the impacts on mortality and the environment would increase the estimated economic costs of climate change.

Using this model, and including those elements of the analysis that can be incorporated at the moment, we estimate the total cost over the next two centuries of climate change associated under BAU emissions involves impacts and risks that are equivalent to an average reduction in global per-capita consumption of at least 5%, now and forever. While this cost estimate is already strikingly high, it also leaves out much that is important.

The cost of BAU would increase still further, were the model systematically to take account of three important factors:

- First, including direct impacts on the environment and human health (sometimes called 'non-market' impacts) increases our estimate of the total cost of climate change on this path from 5% to 11% of global per-capita consumption. There are difficult analytical and ethical issues of measurement here. The methods used in this model are fairly conservative in the value they assign to these impacts.
- Second, some recent scientific evidence indicates that the climate system may be more responsive to greenhouse-gas emissions than previously thought, for example because of the existence of amplifying feedbacks such as the release of methane and weakening of carbon sinks. Our estimates, based on modelling a limited increase in this responsiveness, indicate that the potential scale of the climate response could increase the cost of climate change on the BAU path from 5% to 7% of global consumption, or from 11% to 14% if the non-market impacts described above are included.
- Third, a disproportionate share of the climate-change burden falls on poor regions of the world. If we weight this unequal burden appropriately, the estimated global cost of climate change at 5-6°C warming could be more than one-quarter higher than without such weights.

Putting these additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in consumption per head, now and into the future.

In summary, analyses that take into account the full ranges of both impacts and possible outcomes - that is, that employ the basic economics of risk - suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range.

Economic forecasting over just a few years is a difficult and imprecise task. The analysis of climate change requires, by its nature, that we look out over 50, 100, 200 years and more. Any such modelling requires caution and humility, and the results are specific to the model and its assumptions. They should not be endowed with a precision and certainty that is simply impossible to achieve. Further, some of the big uncertainties in the science and the economics concern the areas we know least about (for example, the impacts of very high temperatures), and for good reason - this is unknown territory. The main message from these models is that when we try to take due account of the upside risks and uncertainties, the probability-weighted costs look very large. Much (but not all) of the risk can be reduced through a strong mitigation policy, and we argue that this can be achieved at a far lower cost than