Institution: University of Cambridge

Unit of Assessment: 19 - Business and Management Studies

Title of case study: The PAGE2002 model of climate change

1. Summary of the impact

Hope's research in developing the PAGE2002 model of climate change has been used extensively by government agencies in the UK and US, as well as the IMF and the international community in order to improve their calculations for global carbon emissions and setting carbon emissions targets. The model was used in the UK government's Eliasch Review, in order to calculate the costs and benefits of actions to reduce global deforestation; by the US Environmental Protection Agency, in order to calculate the marginal impact of one tonne of CO_2 emissions; and the IMF, whose calculations using the PAGE2002 model form the basis for their guidance on carbon pricing.

2. Underpinning research

The PAGE2002, introduced in Hope's seminal 2006 IAJ paper (**Ref 1**), is an Integrated Assessment Model of climate change, which: simulates the best scientific information linking greenhouse gas emissions and climate change, calculates how the impacts and abatement costs of climate change could develop over the coming decades or centuries, and estimates the costs and benefits of climate change policies under uncertainty.

The development of the model was grounded in the concern of the international policy community to make an assessment of the impact of climate change. The Third Assessment Report of the Intergovernmental Panel on Climate Change in 2001 was, at the time, the most comprehensive assessment of climate change ever conducted. The report of Working Group II, which looked at impacts, adaptation and vulnerability, listed five reasons for concern about projected climate change impacts:

- Risks to unique and threatened ecosystems,
- Risks from extreme climate events,
- Distribution of impacts,
- Aggregate impacts,
- Risks from future large-scale discontinuities.

The PAGE2002 model was developed to allow all five reasons for concern to be captured in an integrated assessment framework, with a full treatment of uncertainty (**Ref 1**). The model was developed by Hope, (then Senior Lecturer, since 2007 Reader in Policy Modelling), from his earlier PAGE and PAGE95 models (**Ref 2**). It continued to be refined (**Ref 4**), sometimes in collaboration with other researchers (**Ref 5**), until 2009.

The PAGE2002 model was chosen by the Stern Review to calculate the impacts of climate change and the correct price for CO_2 under a broad range of assumptions about the scientific and economic evidence. The Stern Review identified climate change as 'the greatest market failure the world has ever seen', and calculated that the mean cost of climate change could be the equivalent of 5% to 7% of global consumption, or from 11% to 14% if non-market impacts are included. The mean social cost of carbon was calculated to be $85 per tonne of CO_2. Both the total and marginal impact values were calculated using the PAGE2002 model (**Ref 3**). These calculations led the Stern team to conclude that the total and marginal impacts would be higher than previously accepted values, and radically shifted the centre of gravity of the debate about climate change across the world.

3. References to the research

1. Hope, C. (2006) 'The marginal impact of CO2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern', *Integrated Assessment Journal* 6 (1) 19-56 (Cited over 200 times).

2. Plambeck, E. L. Hope, C. and Anderson, J. (1997) 'The PAGE95 model: Integrating the science and economics of global warming', *Energy Economics* 19 (1) 77-101

3. Dietz, S., Hope, C., Stern, N., and 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

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

5. Alberth, S. and Hope, C. (2007) 'Climate modelling with endogenous technical change: Stochastic learning and optimal greenhouse gas abatement in the PAGE2002 model', *Energy Policy* 35 1795-1807

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

7. Johnson, L.T. and Hope, C. (2012) 'The social cost of carbon in U.S. regulatory impact analyses: An introduction and critique', *Journal of Environmental Studies and Sciences* 2 (3) One of only 70 articles chosen for a Press Release, out of 200,000 published by Springer each year.

Awards and Prizes

Dr Hope was a Lead Author and Review Editor for the Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) in 2001 and 2007. The IPCC was awarded a half share of the Nobel Peace Prize in 2007. He was the specialist advisor to the House of Lords Select Committee on Economic Affairs Inquiry into aspects of the economics of climate change in 2005. In 2007, he was awarded the Faculty Lifetime Achievement Award from the European Academy of Business in Society and the Aspen Institute in recognition of over 15 years of ground-breaking work on climate change.

Dr Hope was a member of the steering group for the Royal Society-National Academy of Sciences 'UK-US Sackler Forum on Integrated Assessment Models' in September 2012 (invitation only event).

4. Details of the impact

Dr Hope's PAGE2002 model was used by the Stern Review, widely recognised as the most influential report on the economics of climate change. The member of the Stern team responsible for running the model confirms that '*PAGE2002 was the sole model used by the Review to estimate the economic impact of climate change in money terms. The resulting estimates were a crucial part … [and]… are certainly the most cited part of the Review, not only in academia but also in the policy and public debate. For example, the front pages of several national newspapers in the UK and beyond ran with the estimates*' (**Source 8**). The most high profile users of the PAGE2002 model in the assessment period are the Eliasch Review in the UK (**Source 1**), the US Environmental Protection Agency (EPA) (**Source 3**) and the International Monetary Fund (IMF) (**Source 4**).

The Eliasch Review (2008), an independent report to the UK government on ways to make effective reductions in forest carbon emissions, used the PAGE2002 model to estimate that the mean global economic cost of climate change caused by deforestation could reach $1 trillion a year by 2100 and that the mean net benefits of halving deforestation could amount to $3.7 trillion

over the long term (**Source 1**). The net benefit of avoiding deforestation calculated by the Eliasch Review has helped to advance the case for forests to be included in any future agreements on climate change policies. In doing so, the costs of reducing global carbon emissions will be reduced substantially, and lower costs will mean that a more ambitious overall emissions target will be possible.

The written statement from HM Treasury details the impact of the PAGE2002 model, which puts specific analysis and figures on measures for reducing global deforestation as a policy priority for the international community (**Source 9**). Analysis of costs and benefits by Hope provided a figure for global deforestation that was a central message and considerably strengthened the impact of the Eliasch Review. It is now being used to make evidence-based policy and shape negotiating positions in the United Nations Framework Convention on Climate Change. UK, EU and US governments have used cost estimates from the Eliasch Review to decide on an overall figure of $100 billion required for climate mitigation and adaptation.

The US Environmental Protection Agency (EPA) used PAGE2002 in 2009-10 as one of three integrated assessment models, to estimate the social cost of carbon (SCC) for use in regulatory analyses (**Source 2**). A written statement from the US office of the EPA describes how SCC is incorporated into federal regulations by the EPA; and by NGOs, private sector firms, development banks and others to quantify the climate impacts of their carbon-related decisions (**Source 10**). For example, the Environmental Defense Fund used documentation on the SCC to inform a public utility commission hearing examining new electricity power generation. Following publication of the U.S. government SCC analysis, DOE, EPA, and the U.S. Department of Transportation (DOT) have used its estimates in twenty rulemakings. These rules affect vehicle GHG standards, ECS for domestic appliances and cross-state air pollution, amongst others (**Source 4**).

The US EPA notes that the SCC estimates calculated by them using the PAGE, DICE and FUND models represent the first sustained interagency effort within the US government to develop an SCC for use in regulatory analysis. The appropriate level for the price of carbon has been the subject of debate (**Ref 6, Ref 7**) and featured in the *New York Times* (**Source 5**). Dr Hope's work is continuing to move the policy debate forward on this important issue, for example, his calculations are being used by the EPA to generate revised climate damage estimates, which are incorporated into the cost of electricity generation to ensure the EPA in the US sets the strongest possible carbon emission standards on power plants. In 2007 Dr Hope was described in *The Financial Times* as the '*unsung hero who has finally devised a way of calculating the financial cost of global warming, showing that you can save the planet while keeping the economy healthy*' (**Source 7**).

Hope's work directly impacts on the ability of government to put a price on carbon emissions. This is a concern for all governments. '*Just as every country has a value added tax or a sales tax, every country will put a price on greenhouse gas emissions'* (**Source 6**). In 2012, the head of the IMF, Christine Lagarde, argued in a foreword to a major new IMF report that '*fiscal instruments—carbon taxes or their cap-and-trade equivalents (with auctioned allowances)—can and should form the centrepiece of policies to reduce energy-related carbon dioxide emissions'*. The IMF's guidance on the appropriate carbon price drew explicitly upon investigations performed using the PAGE2002 model in the US and the UK, cited in chapter 4 of their report (**Source 3**).

5. Sources to corroborate the impact

1. Eliasch, J. (2008) '*Climate Change: Financing Global Forests, The Eliasch Review',* chapter 2, 26 – 33, chapter 5, 77 – 80 (UK Office of Climate Change, London). Cited over 250 times (available in supporting evidence)

2. Interagency Working Group on Social Cost of Carbon (2010) *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (United States Government) http://epa.gov/otaq/climate/regulations/scc-tsd.pdf (available in supporting evidence)

3. Ruud de Mooij, I., Parry, W. H. and Keen, M. (Eds) (2012) *Fiscal Policy to Mitigate Climate Change: A Guide for Policymakers* (International Monetary Fund) (available in supporting evidence)

4. Kopp, R. E. and Mignone, B. K. (2012) 'The U.S. Government's social cost of carbon estimates after their first two years: Pathways for improvement' *Economics: The Open-Access, Open-Assessment E-Journal* 6 2012-15 http://dx.doi.org/10.5018/economics-ejournal.ja.2012-15

5. Foster, J. M. (2012) 'The social cost of carbon: How to do the math?' *New York Times* September 18

6. Roodman, D. and de Nevers, M. (2012) 'IMF to the rescue on climate and sustainable development?' *Centre for Global Development* http://blogs.cgdev.org/global_prosperity_wonkcast/2012/06/18/imf-to-the-rescue-on-climate-and-sustainable-development/

7. Bradshaw, D. (2007) 'Economic research that saves the world', *Financial Times*, *Special Report Business Education* p 4 29 January

8. Written Supporting Statement from Member of Stern Review on Climate Change (15 April 2011)

9. Written Supporting Statement from former Deputy Director, PM Office of Climate Change and Senior Economist, HM Treasury (June 2013)

10. Written Supporting Statement from US Environmental Protection Agency (July 3rd 2013)