Institution: University of Sussex

Unit of Assessment: UoA 18 Economics

Title of case study: Estimating the 'social cost of carbon' to reduce US emissions and improve energy efficiency

1. Summary of the impact

The US government's announcement of an increase in the 'social cost of carbon' (SCC) from $24 to $38 a tonne has been made on the basis of research by Richard Tol, of the University of Sussex. Regulation based on the new SCC (a measure of the damage of releasing an additional tonne of carbon into the atmosphere) initially applies to microwave ovens, where it is anticipated to save US consumers billions on their energy bills over coming decades and prevent 38 million tonnes of CO_2 emissions. From June 2013, the new SCC applies to any new or revised regulation by any branch of the US government and will eventually affect a wide range of products and investments, including cars, white goods and power plants.

Tol, who works as an adviser to the US Environmental Protection Agency (EPA), has been instrumental in helping the agency to understand the economic impacts of climate change and the methods and assumptions that underpin SCC estimates. The US government's estimates of the SCC are widely used by other decision-makers in the private sector, banks and NGOs and in other countries.

2. Underpinning research

The social cost of carbon (SCC) is estimated using integrated assessment models (IAMs), which combine models of demography, the economy, energy use, emissions, greenhouse gas cycles, climate and impacts of climate change. The '*Climate Framework for Uncertainty, Negotiation and Distribution*' (FUND) is an IAM developed by Richard Tol and his students, notably David Anthoff (UC, Berkeley). FUND is a dynamic computer model that continually updates in the light of changing assumptions and new estimates of key parameters. Modelled impacts include agriculture, forestry, sea levels, a range of diseases, energy use, water resources, unmanaged ecosystems, and tropical and extra-tropical storm impacts.

The source code, data and a technical description of the model are available at http://www.fund-model.org. The most recent version (FUND 3.7) was developed on the basis of Tol's research in 2012–13. The research papers in Section 3, R1–R6, have all informed the development of the FUND 3.7 software in terms of providing improved estimates and sensitivity analysis with respect to key parameters of the model. R3 describes the model (an earlier version was published as a working paper in September 2011; the published article uses a later version of the model, developed in 2012).

FUND is considerably more complex than other IAMs and is able to assess the relative importance of parameters not included in other models, such as the sensitivity of different sectors and regions to climate change and changes in vulnerability and relative prices with development. FUND 3.7 is the first sophisticated version of this software to investigate the relative contribution of all uncertain parameters on the SCC, when all parameters are varied simultaneously. It is this version that has been instrumental in producing the new estimates of the SCC adopted by the US government.

There is large uncertainty about the SCC. R3 analyses the structure of that uncertainty using FUND 3.7 by providing a decomposition of the relative contribution of key parameters to the variation in the estimates of the SCC. This also sets the priorities for further research. For example, increased demand for air-conditioning in response to climate change and economic growth emerge

as important yet poorly understood parameters.

R5 and R2 provide the first estimates of the economic impact of ocean acidification, a problem closely related to climate change and also caused by CO_2 emissions. R1 uses FUND to investigate the 'Schelling conjecture', which asserts that economic development provides the best defence against the impact of climate change. Thus, under this notion, poverty implies vulnerability to climate change, and accelerated economic growth may therefore be more cost-effective than emission abatement in reducing the impact of climate change. The study shows that this holds only for the least-developed countries.

R6 estimates the SCC as a function of the uncertainty about climate change and demonstrates that emission reduction puts an upper bound on the expected value of the SCC – extending Weitzman's '*Dismal Theorem*', which states that society faces an arbitrarily large expected loss from 'fat tails' or high-consequence, low-probability scenarios. The research shows that this only holds *without* climate policy. Greenhouse gas-emission reduction rapidly thins the undesirable tail.

R4 considers alternative criteria for decision-making under fat-tailed uncertainty, such as minimax regret, minimum tail risk and thinnest tail. The authors find that the implied carbon prices corresponding to these different criteria do not differ much from the SCC now advocated by the US government on the basis of Tol's research.

3. References to the research

R1 Anthoff, D. and Tol, R.S.J. (2012) 'Schelling's conjecture on climate and development: a test', in Hahn, R.W. and Ulph, A. (eds) *Climate Change and Common Sense. Essays in Honour of Tom Schelling*. Oxford: Oxford University Press, 260–73.

R2 Narita, D., Rehdanz, K. and Tol, R.S.J. (2012) 'Economic costs of ocean acidification: a look into the impact on shellfish production', *Climatic Change*, 113(3–4): 1049-–63.

R3 Anthoff, D. and Tol, R.S.J. (2013a) 'The uncertainty about the social cost of carbon: a decomposition analysis using FUND', *Climatic Change*, 117(3): 515–30.

R4 Anthoff, D. and Tol, R.S.J. (2013) 'Climate policy under fat-tailed risk: an application of FUND', *Annals of Operations Research*, DOI 10.1007/s10479-013-1343-2.

R5 Brander, U.M., Rehdanz, K., Tol, R.S.J. and van Beukering, P.J.M. (2012) 'The economic impact of ocean acidification on coral reefs', *Climate Change Economics*, 3(1): 1–29.

R6 Hwang, I.C., Reynes, F. and Tol, R.S.J. (2013) 'Climate policy under fat-tailed risk: an application of DICE', *Environmental and Resource Economics*, 56(3): 415–36.

Outputs can be supplied by the University on request.

4. Details of the impact

The 'social cost of carbon' (SCC) is an estimate of the monetary value of the damages associated with a small increase in CO_2 emissions. The figure is meant to approximate losses from incremental climate change, such as flood damage, disease, diminished crop production, etc. Conversely, this monetary figure also represents the value of damages avoided for a given emissions reduction.

In the United States, the SCC is incorporated into the cost–benefit analyses of measures to reduce CO_2 emissions. Until 2010, different federal agencies used, if at all, a range of estimates for the SCC. Since then a dozen agencies, from the EPA to the Department of Transportation, decided to standardise their estimates of the SCC. The original estimate was set at $21 per tonne of CO_2 in 2010 by a working group of experts from several government agencies, led by the Council of

Economic Advisers and the Office of Management and Budget.

These initial estimates of the SCC in 2010 derive from estimates provided by an earlier version of the FUND model and two other Integrated Assessment Models: DICE (Yale University) and PAGE (Cambridge University). These estimates have been used to justify more stringent fuel efficiency standards for new motor vehicles (EPA and Department of Transportation 2010) [see Section 5, C5] and energy efficiency standards for many appliances (Department of Energy 2012) [C4]. The Federal Register reveals that the SCC has been cited in 31 rules.

Richard Tol has worked as a consultant and adviser to the EPA since 2007. In this role, he has been instrumental in helping the EPA to understand the economic impacts of climate change and the methods and assumptions that underpin estimates of the SCC. The FUND model has been developed by Tol to study climate policy. Improvements and modifications to the model are conducted by Tol with Anthoff and their collaborators. EPA staff have been trained in the use of the FUND model. The application of the latest peer-reviewed version of the model is performed by EPA staff under the guidance of Tol and Anthoff.

In May 2013, the Obama administration increased the SCC to be used by federal agencies to $38 per tonne of carbon. The new SCC recommendations of the InterAgency Working Group draw on the revised version of the FUND (FUND 3.7) model along with estimates from the other two IAMs. This model, and the associated revisions, derive from Tol's research.

The new SCC currently applies only to energy-efficiency regulations for microwave ovens (Department of Energy 2013) [C1]. However, the standardisation of rates in 2010 means that it will apply to *any* new or revised regulation by *any* branch of the US government from June 2013 onwards. Consequently, the potential reach of this impact is large as, over time, the new SCC will be extended to energy-efficiency regulations covering all appliances, vehicles, machinery and buildings. Proposed rules have been issued for metal halide lamp fixtures, commercial refrigeration equipment, walk-in coolers and freezers, and residential furnace fans.

However, even the impact of the new microwave legislation alone on both consumers and the environment is substantial. The higher cost of carbon implies that the estimated environmental damage from inefficient microwave ovens is much higher than previously calculated. The legislation applies to their energy use when in standby mode. Consequently, producers will be forced to withdraw inefficient microwave ovens from the marketplace, resulting in significant energy savings for consumers and a reduction in greenhouse gas emissions. Estimates suggest $2.3 billion of savings for consumers over coming decades and a reduction of 38 million tonnes in CO_2 emissions (Department of Energy 2013) [C1].

The revised SCC is already being used in draft legislation in a number of key areas. The SCC is used to underpin the draft rules for methane leaking from shale oil and gas extraction, and for CO_2 emissions from new power plants (the final rule is in preparation http://epa.gov/carbonpollutionstandard/index.html – see EPA (2012) [C6] for the regulatory impact analysis of the proposed rule). The latter rules aim to make coal-fired electricity less competitive.

The new SCC estimates are also feeding into proposed effluent regulations for power plants (EPA 2013) [C2]. The EPA is proposing regulation that would strengthen the controls on discharges from certain steam electric power plants. These plants currently contribute 50–60 per cent of all toxic pollutants discharged into US surface waters. The EPA is considering four possible options for legislation, which have a large potential for emissions reductions.

The revised SCC has already had direct impact on legislation for microwave ovens. It is being used in draft legislation for power plants. Any change in legislation from June 2013 will adopt the revised SCC. On 25 June 2013, President Obama outlined his 'Climate Action Plan' (Obama 2013) [C8]. This includes a raft of proposed legislation to cut US CO_2 emissions over the coming decades. Implicit in these regulations is the newly adopted SCC. Consequently, the current impact of Tol's work will expand across a wide range of policy areas in the United States in future decades.

5. Sources to corroborate the impact

C1 Department of Energy (2013) 'Energy conservation program: energy conservation standards for standby mode and off mode for microwave ovens', *Federal Register*, 78(116): 36315–68.

C2 Environmental Protection Agency (2013) 'Effluent limitations guidelines and standards for the steam electric power generating point source category', *Federal Register*, 78(100): 34432–543.

C3 Interagency Working Group on the Social Cost of Carbon (2013) *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Technical Support Document: http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf.

Background documentation

C4 Department of Energy (2012) 'Energy conservation program: energy conservation standards for dishwashers', *Federal Register*, 77(190): 59712–16.

C5 Environmental Protection Agency and Department of Transportation (2010) 'Light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards: final rule', *Federal Register*, 75(88): 25324–728.

C6 Environmental Protection Agency (2012) *Regulatory Impact Analysis for the Proposed Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units*. Washington, DC: Environmental Protection Agency (EPA-452/R-12-001).

C7 Interagency Working Group on the Social Cost of Carbon (2010) *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*.Technical Support Document: http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf

C8 Obama, B.H. (2013) *The President's Climate Action Plan*. Washington, DC: White House: https://docs.google.com/file/d/0B88iFXWgVKt-U0tHWlR0SzhqOTg/edit.

Testimonials

- Economist at the US Environmental Protection Agency:

  The estimates of carbon mitigation benefits supported by Professor Tol's educational outreach and training have thus far been used in the analysis of over 20 significant regulations within the United States. The estimates have also been used by other nations and organizations to assess decisions that affect carbon pollution. Professor Tol's research and educational outreach has been highly valuable in ensuring that policy makers have had access to the scientific information required to understand and support their decisions.

- Director, National Center for Environmental Economics, US Environmental Protection Agency:

  While the SCC allows us to make sure decision-makers account for the climate implications of our regulations, perhaps equally important, many NGOs, private-sector firms, development banks, and other countries are also using our SCC to quantify the climate impacts of their carbon-related decisions. For example, the Environmental Defense Fund submitted our Technical Support Document on the SCC into a public utility commission hearing examining new electric power generation. Many states and local governments are also using the SCC in their policy analyses.'