Supporting Information

Nordhaus 10.1073/pnas.1609244114

Model Version

The base file for calculating the SCC is DICE2016R-091916s.gms. This is updated from the version of May 2016, with the primary change since the May version being the damage function. It runs for 500 y starting in 2015 over 5-y increments. The code is available on the website. The estimated SCC for 2015 in 2010 US international dollars is 31.20 per ton of CO_2. If set up in the General Algebraic Modeling System (GAMS) program, the results are in an output file named "Dice2016RResults.csv." Major changes are as documented in the manuscript. Other details are contained here. The models and discussion are available at www.econ.yale.edu/~nordhaus/homepage/DICEmodels09302016.htm.

Federal Regulations Using the SCC

The SCC has been used in many small and large federal regulations pertaining to the environment and energy. A recent compilation of costs and benefits as calculated in regulatory impact analyses is contained in ref. 15 and is also discussed in ref. 2. Important examples totaling over $500 billion in total benefits are ones relating to automobile fuel efficiency standards and power plants.

Growth-Corrected Discounting

Fig. 3 shows the importance of the growth-corrected discount rate in determining the SCC. This section describes that point further, drawing on ref. 2. Assume that we linearize all of the equations of the DICE model and that all environmental variables have reached a stationary state where emissions, concentrations, population, temperature, and other physical variables are constant. Output, consumption, and damages are growing at constant rate g, and the goods discount rate is r. If we perturb emissions by 1 unit, this will cause a path of damages that is distributed over the distant future. For simplicity, assume that the damages start immediately but the damage–output ratio declines at a decay rate of δ per year.

We can use the Ramsey equation to evaluate the SCC as a function of the key variables. The Ramsey equation provides the equilibrium rate of return in an optimal growth model with constant growth in population and per capita consumption without risk or taxes. In this equilibrium, the real interest rate (r) equals the pure rate of social time preference (ρ) plus the rate of growth of per capita consumption (g) times the consumption elasticity of the utility function (α). In long-run equilibrium, we have the Ramsey equation $r = \rho + \alpha g$. The key variable will be the growth-corrected discount rate, $r - g$. Under our assumptions, $r - g = \rho + (\alpha - 1)g$. To simplify, assume that $\alpha = 1$, or that the utility function is logarithmic, which implies that $r - g = \rho$. [These long-run growth and discounting assumptions are used in *The Stern Review* (10) and are approximately the case for the DICE model.] Under these assumptions, the SCC is proportional to $1/(\rho + \delta)$. This relationship is shown by the near-hyperbolic curve in Fig. 3.

Damage Function Revision

The major change in DICE-2016R is the method for estimating the damage function. In earlier versions until 2010, we relied on either estimates gathered by the team at Yale or by surveys. The 2013 version relied on the Tol survey of damages (6, 7). This survey contained numerous errors and could not be used in the present version. The basic method for setting the damage function was similar to that in the DICE-2013R model as described in ref. 3. The method for calculating the damage function is described here.

We examined different damage estimates and used these as underlying data points and then fitted a regression to the data points. We also added an adjustment of 25% for omitted sectors and nonmarket and catastrophic damages, as explained in ref. 3.

The new estimates start with the survey of damage estimates by the author and Andrew Moffat. The survey included 26 studies. Of these, 16 contained independent damage estimates and were included, and, of these, 9 received full weight. Those receiving less than full weight were ones that were earlier (but different) versions of a model (for example, the FUND model) or had serious shortcomings. If a study had several estimates (say, along a damage function), the sum of the weights was constrained to be 1.

The estimates were made using four techniques. The central specification was a one-parameter quadratic equation with a zero intercept and no linear term. Unweighted least squares and median regressions generally had lower coefficients than the weighted versions. The weighted ordinary least squares (OLS) estimates had slightly higher coefficients than the weighted median regression. Additionally, the tests were made with different lower bound thresholds from 0 °C to 4 °C, and upper bound estimates from 3 °C to 10 °C, but these made virtually no difference to the estimates. A specification with both linear and quadratic terms was extremely unstable and was rejected.

The final estimate was an equation with a parameter of −0.236% loss in global income per degree Celsius squared; this leads to a damage of 2.1% of income at 3 °C, and 8.5% of global income at a global temperature rise of 6 °C. This coefficient is slightly smaller than the parameter in the DICE-2013R model (which was −0.267% per degree Celsius squared). The change from the earlier estimate is due to corrections in the estimates from the Tol numbers, inclusion of several studies that had been omitted from that study, greater care in the selection of studies to be included, and the use of weighted regressions.

The uncertainty of the damage coefficient is an ingredient in the uncertainty analysis discussed in *Uncertainty Estimates*. From a technical standpoint, the t statistic on the estimated coefficient is −7.8, so it is extremely well determined. However, this estimate does not reflect specification uncertainty, parameter uncertainty, or study dependence. As an illustration, the prediction of the different specifications at 3 °C is 3.8 times the SD for the one-parameter specification and 2.2 times the SD for the two-parameter specification. We have taken a polar value for the uncertainty of the damage parameter that is one-half the parameter. This value reflects the great divergence today among different studies.

Decomposition of the Change in SCC

Calculating the decomposition of the SCC by major change is straightforward. It involves introducing parametric changes in a cumulative fashion. For example, the change in "Economics" involves using the earlier value of world GDP and productivity growth instead of the 2016 version.

Regional Estimates of SCC

The regional estimates of the SCC are drawn from ref. 2 for the three IAMs. The discounted value of GDP for different regions is constructed as follows: We took estimates of 2020 GDP for countries and regions from the IMF World Economic Outlook database for April 2016.

Uncertainty Estimates

To estimate the uncertainty of the SCC, we discretized the distributions of three key uncertain variables and estimated the SCC for each discrete combination. More precisely, the probability density functions (pdfs) for the variables were taken from the MUP (5) study for ETS and productivity growth and from the damage survey for the damage coefficient. The means and SDs of the variables were (0.236, 0.118)% of income per degree Celsius squared for the damage parameter, (3.10, 0.84) °C for equilibrium CO_2 doubling for the ETS, and (1.52, 1.00)% per year for initial-period productivity growth.

The pdfs for each of the three uncertain variables were divided into deciles, and the mean of each decile was calculated for each uncertain variable. The mean for each variable across its deciles was therefore the mean of the variable; this produces 1,000 equally probable states of the world, and runs were made for each state of the world with no policy. In terms of decision theory, these are an "act, then learn" set of outcomes. The SD of the SCC for 2015 was $31.5 per ton of CO_2.