Roll the DICE Again: Economic Models of Global Warming

Chapter 5

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Chapter 5. The DICE-99 Model

Earlier chapters have discussed the development of RICE-99. For many purposes, particularly when the regional details are inessential, it is convenient to have a simplified version of the model. With this goal in mind, we have developed a globally aggregated model, which is called DICE-99.

While losing the regional detail of RICE-99, DICE-99 has several advantages. It is more useful for understanding the basic structure of economic policy issues posed by greenhouse warming because it is sufficiently small so that researchers can understand the individual linkages in an intuitive way. It is more easily modified because the number of parameters is far smaller. It is much faster, so that alternative experiments can be tested more easily. And it can be run much further into the future so that the implications of alternative time horizons, discounting assumptions, and carbon or climate models can be more easily traced out. Researchers or policy makers who are interested in having an intuitive understanding of the economics of global warming are well-advised to begin with DICE before tackling more opaque and computationally demanding models such as RICE or other large-scale models.

1. Model Structure

The basic structure of DICE-99 parallels RICE-99 in most sectors. The equations of DICE-99 are provided in Appendix B, while the computer code for DICE-99 is provided in Appendix E. The major difference between the two models lies in the production sector, where the reduced form approach of the original DICE-94 model has been retained. More specifically, the major elements of DICE-99 are the following:

1. The geophysical sectors in DICE-99 are identical to RICE-99. The reason is that the carbon cycle, radiative forcing, and climate equations are globally aggregated, so there is no reason to differentiate between the RICE and DICE models in these segments.

2. The treatment of the pure rate of time preference is identical for the RICE and DICE models.

3. The modeling structure for population, economy-wide technological change, labor inputs, investment, and the capital stock are identical. The only difference is that DICE represents the globally aggregated magnitudes, while RICE considers each of these variables separately for each region.

4. The damage equation takes the same form in the RICE and DICE models.

5. The major difference between the two models lies in the treatment of production

and energy. As described above, RICE-99 introduces a more complete model of the energy sector, with carbon-energy entering as an intermediate input in the production function; DICE-99 uses a simplified reduced-form treatment of production. The DICE model has a Cobb-Douglas production function in labor, capital, and exogenous technological change. Base industrial carbon emissions are given by the product of a carbon-intensity factor times output, $\sigma(t)$, which is the ratio of uncontrolled industrial CO_2 emissions to global output. In runs where CO_2 emissions are controlled, emissions are reduced by the control rate, $\mu(t)$; controlled emissions are equal to base emissions times one minus the control rate. Net output is then gross output times a factor that is a function of the emissions control rate and the damages from climate change.

6. The final difference between the two models is the energy supply sector. In RICE-99, we explicitly model the exhaustion of carbon-energy. In DICE-99, we remove all constraints on total use of carbon fuels. In other words, there are no scarcity constraints on cumulative carbon-energy use in DICE-99.[1]

In summary, DICE-99 is very similar in structure to the original DICE model. Those who are familiar with the earlier model will find that the new DICE version requires little learning time and is easy to use and manipulate. The new model is available in both a GAMS version and an EXCEL spreadsheet version, which means that the model can be used with inexpensive and widely available software. The major change from the previous version is recalibration to fit the new findings of the larger and more accurate economic structure of RICE-99. In addition, minor changes are made in the specification of certain parts of the model.

2. Calibration

DICE-99 was calibrated so that the output from its base run and its optimal run would fit the corresponding runs of RICE-99. The following explains the approach to calibration. Because of the highly divergent patterns of regional development, the fit between disaggregated RICE and aggregated DICE was imperfect, so the RICE and DICE models provide different projections for some variables.

The base case is described in Chapter 2, section 5. The optimal run in DICE maximizes global utility subject to the major economic and physical constraints (a full listing is provided in Appendix B). The optimal run in RICE-99 found a time path of carbon emissions that is Pareto optimal . Further description of the base and optimal runs can be found in Chapter 6 and Chapter 7, section 2.

Population, carbon intensity, the initial capital-output ratio, and economy-wide technological change are exogenous variables in DICE. These were set so that the paths of global population, global output, global emissions, CO_2 concentrations, and global temperature for the base run of DICE-99 matched those for the base run of RICE-99 over the first 13 periods (130 years).

We now give a more detailed discussion of the calibration procedure. Population was calibrated so that it closely matched the path of aggregate population in RICE-99. Next the initial capital stock was calibrated so that the initial DICE-99 real return on capital was equal to the output-weighted average real rate of return across regions in RICE-99. Next, the initial level, initial growth rate, and decline in the growth rate of total factor productivity in DICE-99 were set to match the initial level of output, the average output level in the first four periods, and the average output level in the first eleven periods in RICE-99.

Next, the level of the initial carbon-output ratio, $\sigma(0)$, was set so that emissions in the first period matched actual emissions. Then, the decline in $\sigma(t)$ was set so that the path of global temperature in DICE-99 tracked RICE-99.

Table 5-1 and Figure 5-1 show the percentage error of DICE-99 relative to RICE-99 for the important variables in the base run. As can be seen, the average error for the important climatic variables is less than 2 percent over the next century.

The next step was to have the optimal run of DICE-99 match the optimal run of RICE-99. For this step, we adjusted the parameters of the damage and emissions-control cost functions of DICE. More precisely, note that the cost of abatement function in DICE takes the form $Cost(t)/Y(t) = [1- b_1(t)\mu(t)^{b2}]$, where $\mu(t)$ is the emissions-control rate.[2] The coefficients $b_1(t)$ and b_2 and those of the quadratic damage function were set so that the optimal carbon tax and emissions control rates in DICE-99 matched the projections of these variables in the optimal run of RICE-99.

Table 5-2 and Figure 5-2 show the calibration errors for the optimal run. The average errors for the first 12 periods (DICE-99 relative to RICE-99) are 1.6 percent for industrial emissions, 0.4 percent for concentrations, 0.5 percent for temperature increase, 3.5 percent for the carbon tax, and 2.3 percent for the emissions-control rate. In short, the calibrated DICE-99 model is a faithful reflection of RICE-99.

A final word will be helpful for those contemplating whether to use the RICE or DICE model as research tools. DICE is much easier to use and runs much more quickly. The two models track closely for the first 150 years, after which numerical approximations and the shorter time horizon become a problem in RICE. For looking at longer-run tradeoffs, particularly those that do not involve regional analyses, DICE is a more accurate instrument and much easier to use. Problems can arise in either model when it is run too far outside the area for which it was designed and calibrated. For example, in DICE, increasing economic growth rates, population, or carbon intensities may increase total use of carbon fuels well beyond current estimates of availability. By contrast, RICE-99 contains an upward-sloping supply curve for fossil-fuels, and this constraint prevents excessive cumulative emissions. Caution should be taken to ensure that analyses using the models do not violate implicit assumptions used to simplify the model.

Table 5-1
Comparison of RICE-99 and DICE-99 Results, Reference Case

[Ratio of Calculation for DICE-99 to RICE-99]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
World GDP	1.002	1.016	1.034	1.046	1.053	1.046	1.030	1.008	0.983	0.956	0.929	0.902
World GDP/capita	1.002	1.017	1.035	1.047	1.054	1.047	1.031	1.009	0.983	0.956	0.928	0.901
World Population	1.000	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	1.000	1.001	1.001
Industrial Emissions	1.000	0.999	1.012	1.026	1.037	1.041	1.039	1.033	1.023	1.011	0.999	0.987
Total Emissions	1.000	0.999	1.011	1.023	1.034	1.038	1.037	1.031	1.022	1.011	0.999	0.988
Industrial CO2/Output ratio	0.999	0.985	0.980	0.983	0.988	0.999	1.014	1.030	1.047	1.064	1.082	1.102
Concentrations	1.000	1.000	1.000	1.001	1.003	1.006	1.008	1.009	1.010	1.010	1.009	1.008
Global Temperature	1.000	1.000	1.000	1.000	1.001	1.004	1.007	1.010	1.012	1.013	1.013	1.012
Cumulative Total Emissions	1.000	1.000	1.004	1.009	1.015	1.019	1.022	1.023	1.023	1.022	1.019	1.016
Average Concentration	1.000	1.000	1.000	1.000	1.001	1.002	1.003	1.004	1.005	1.005	1.006	1.006
Average Temperature	1.000	1.000	1.000	1.000	1.000	1.001	1.003	1.004	1.006	1.007	1.008	1.008

Table 5-2
Comparison of RICE-99 and DICE-99 Results, Optimal Case

[Ratio of Calculation for DICE-99 to RICE-99]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
Total Emissions	0.999	0.996	1.006	1.018	1.029	1.034	1.034	1.030	1.023	1.015	1.005	0.995
CO2/Output ratio	0.997	0.981	0.975	0.977	0.982	0.993	1.009	1.027	1.046	1.066	1.086	1.107
Industrial Emissions	0.998	0.996	1.007	1.020	1.032	1.036	1.036	1.032	1.024	1.015	1.005	0.995
Cumulative Total Emissions	0.999	0.997	1.001	1.005	1.011	1.015	1.018	1.020	1.020	1.020	1.018	1.016
Carbon control rate	1.044	1.066	1.082	1.082	1.072	1.055	1.033	1.010	0.986	0.965	0.948	0.936
Carbon tax	1.000	1.033	1.059	1.071	1.076	1.073	1.063	1.048	1.030	1.009	0.987	0.966
Concentrations	1.000	1.000	1.000	1.000	1.002	1.004	1.006	1.008	1.009	1.009	1.009	1.008
Global Temperature	1.000	1.000	1.000	0.999	1.000	1.002	1.005	1.007	1.009	1.011	1.011	1.011
Average Concentration	1.000	1.000	1.000	1.000	1.000	1.001	1.002	1.003	1.003	1.004	1.005	1.005
Average Temperature	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.003	1.004	1.005	1.006	1.007

Fig 5-1. Calibration Error in DICE Reference Case

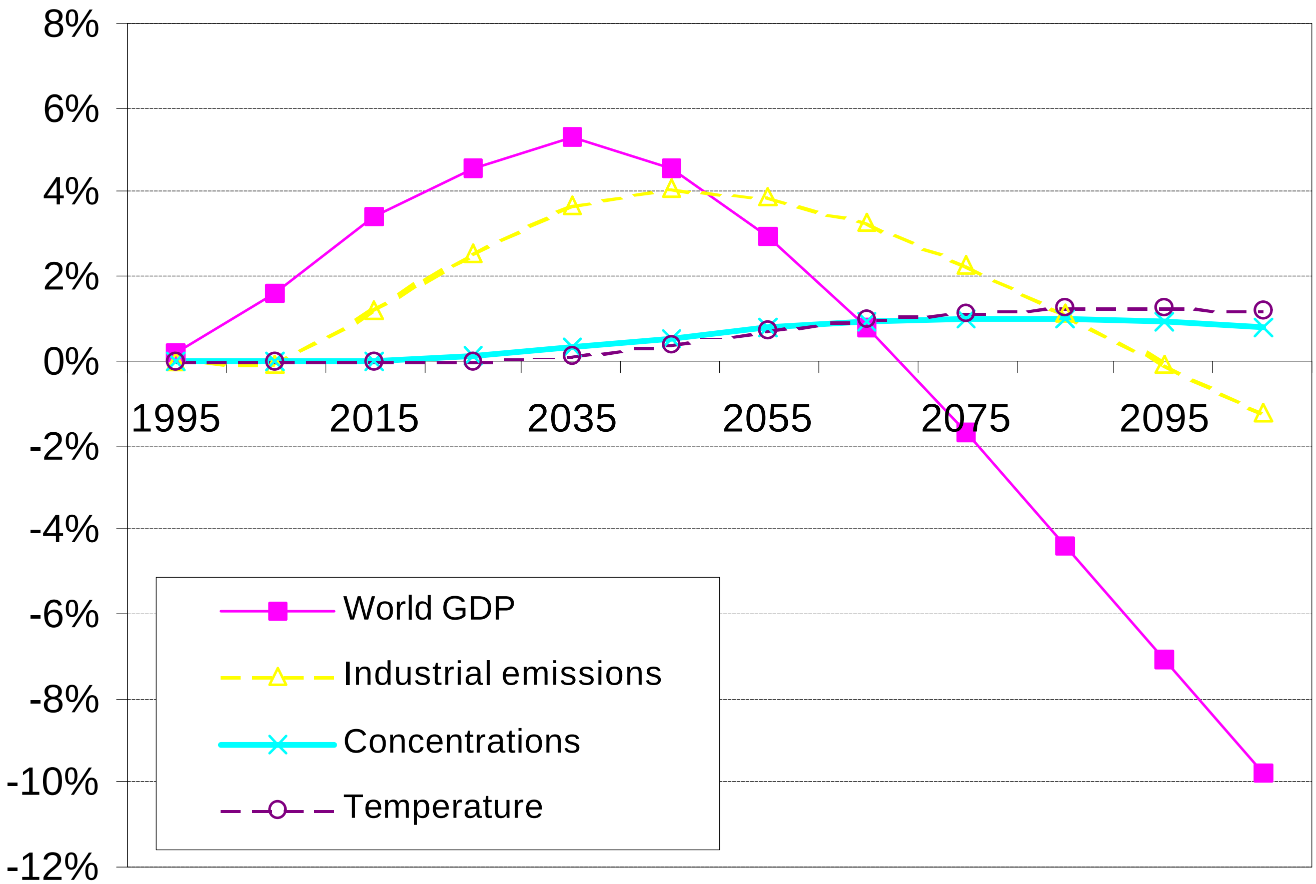
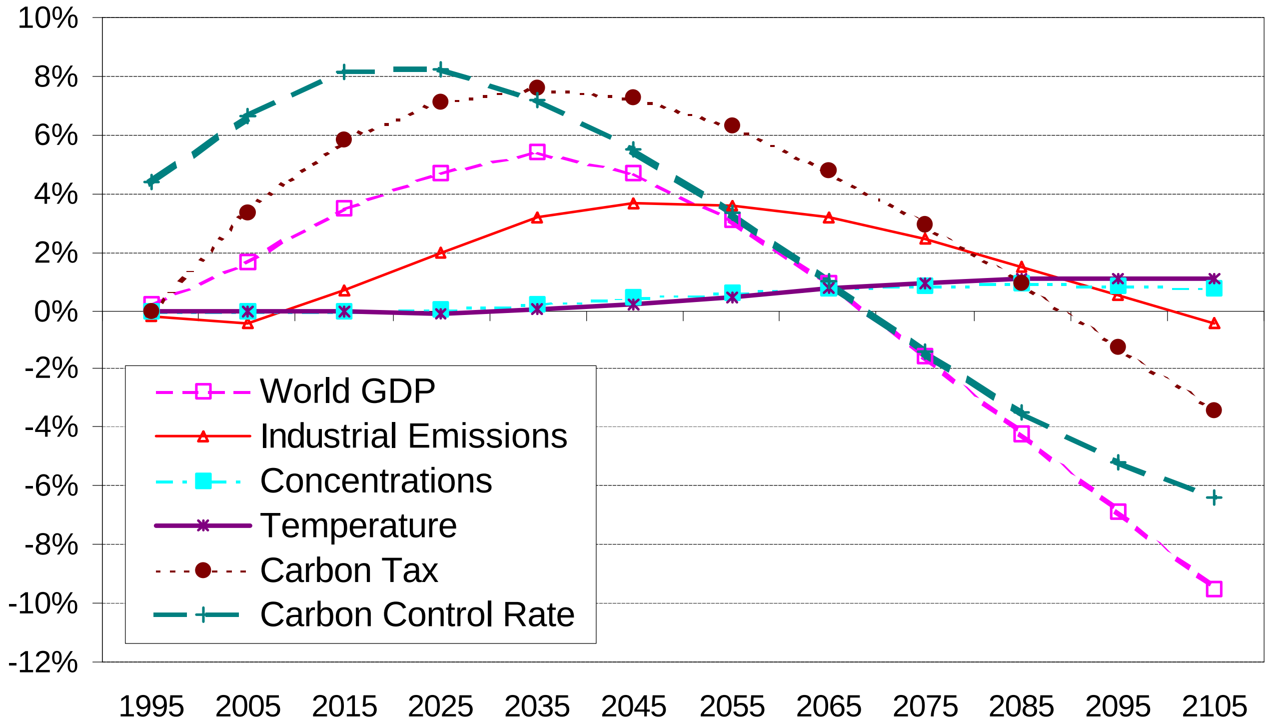


Fig. 5-2 Calibration Error in DICE Optimal Run



Endnotes:

1. Carbon scarcity cannot be easily introduced in the DICE framework because of the reduced-form treatment of emissions reductions. Substitution away from carbon fuels occurs only when the emissions-reduction variable (μ) is allowed to take non-zero values. The base case constrains μ to be zero. Scarcity-induced (as opposed to climate-policy-induced) substitution away from carbon fuels cannot be incorporated easily in this framework. Test runs using the standard version of DICE-99 indicate that there is no substantial impact of scarcity of carbon fuels for over 100 years. More precisely, if carbon scarcity similar to that in RICE-99 is introduced in DICE, a small Hotelling rent on carbon fuels will come into play. The calculated Hotelling rent on carbon fuels is about $0.50 per ton carbon in 2000 and around $26 per ton carbon in 2100. This is suppressed in DICE, leading to slightly higher emissions and climate change. The difference in global mean temperature between the carbon-scarce and carbon-superabundant runs is however extremely small for two centuries— 0.018 ºC in 2100 and 0.13 ºC in 2200.

2. If $E_b(t)$ is industrial emissions in the baseline, the emissions control rate for period t, $\mu(t)$, is $[E_b(t)-E(t)]/E_b(t)$.