# 4 Notes from Nordhaus A question of balance

## 4.1 Chapter 1. Summary for concerned citizen

1. CBA. Balance today's economic costs of abatement with future economic and ecological benefits. DICE is about balancing costs and benefits.

2. 2006 global emissions of $CO_2$ was 7.5 billion tons of carbon (not $CO_2$). Driving 10,000 miles emits about 1 ton of carbon. $CO_2$ weight is 3.67 times larger than carbon weight. The average house emits 3 tons if electricity is coal generated. The US emits 5 tons per person. For the world, 1.25 tons per person.

3. 9 giga-tons of carbon is 33 giga-tons of $CO_2$ and raises concentration by 4ppm. A giga-ton is 1,000,000,000 tons (1 billion).

4. Questions to answer:

   (a) How sharply should emissions be reduced?

   (b) What is the optimal time profile of emissions reductions?

   (c) How to distribute the reductions across industries and countries

   (d) Should emission limits be imposed on firms, industries and nations, or should we use taxes on GHGs?

   (e) What is the relative contribution of rich and poor countries?

5. DICE stands for Dynamic Integrated model of Climate and Economy.

   (a) Exogenous variables: population, stocks of fossil fuels pace of technological change.

   (b) Endogenous variables: world GDP, capital stock, $CO_2$ emissions/concentrations, temperature change, climate damages.

   (c) Policy response of emission reductinos or carbon taxes.

6. The DICE model from the book thinks BAU will cost 2.5 percent of world GDP per year through 2100. Damages most concentrated on low income and tropical regions, although some countries may benefit from climate change.

7. DICE uses 4 percent discount rate.

8. DICE estimates SCC to be $30 per ton of carbon. Hence, annual socal cost per person in USA is $150 per year. A $30 carbon tax is 9 cents per gallon of gas.

9. Argument against subsidies for green technology: Too many activities to subsidize (bicycles, walking?) There are insufficient resources to subsidize all low emitting activities. Too complicated to compute the right subsidy for each activity. Subsidies generate environmental rent seeking, e.g., ethanol subsidies. Subsidies divert responsibility for cleaning up to other areas.

## 4.2 Chapter 2. Background and Description of DICE model

1. The first steps to slow warming was around 1992 under the UN Framework Convention on Climate Change. The first binding int'l agreement was Kyoto Protocol (2005). The first period for emissions reductions was 2008-2012. The UEU's Emission Trading Scheme (2006) covers half of Europe's emissions.

2. Problem with Kyoto is US withdrew in 2001, then other countries left.

3. DICE is a global model.

# 5 From DICE Simplified (Ikefuji Laeven, Magnus, and Muris) DICE 2016R model

DICE is a growth model. In growth theory, you reduce today's consumption to invest in capital so that you can have higher consumption tomorrow. In DICE, you can make climate investments, that are like capital investments. Climate investments improves quality of future life.

1. Output is Cobb-Douglas with exogenous technology and standard capital accumulation

$$Y_t = A_t K_t^{-\gamma} L_t^{1-\gamma} \tag{11}$$

$$K_{t+1} = (1-\delta) K_t + I_t \tag{12}$$

2. There are industrial (from $Y_t$) and land-use ($E_t^o$) $CO_2$ emissions.

$$E_t = \sigma_t (1-\mu_t) Y_t + E_t^o \tag{13}$$

   Emissions are bad. $\sigma_t$ is the (exogenous) emissions generated per unit GDP. This is the uncontrolled industrial emission intensity. Total emissions are the uncontrolled emissions reduced by the emissions reduction rate, $\mu_t$, which is a planner choice variable. If there is abatement going on, output produces less emission. $E_t^o$ is non-industrial emission.

   Note: The decade 2001-2010 showed relatively low decarbonization. Global $CO_2$/GDP (i.e., $\sigma_t$) changed at -0.8% per year. From 2000-2015, it changed at -2.1% per year. Maybe is the result of climate policies. The path of $\sigma_t$ is assumed and exogenous. Nordhaus (2017) assumes change of -1.5% per year.

3. Carbon cycle is a three-reservoir model, calibrated to carbon-cycle models. Let $M_t$ be the stock of carbon in atmosphere. The reservoirs are (i) upper ocean and biosphere mising reservoir, (ii) deep ocean, which provides a finite, vast carbon sink for the long run, and (iii) atmosphere,. $X_{1,t}$ is $CO_2$ concentration in upper ocean and biosphere. $X_{2,t}$ is the concentration in the deep ocean.

$$X_{1,t+1} = b_0 M_t + (1-b_1-b_3) X_{1,t} + b_2 X_{2,t} \tag{14}$$

$$X_{2,t+1} = b_3 X_{1,t} + (1-b_2) X_{2,t} \tag{15}$$

$$M_{t+1} = (1-b_0) M_t + b_1 X_{1,t} + E_t \tag{16}$$

4. Temperature. $H_t$ is temperature deviation from 1900, in Celsius. It is the world average temperature. Let $Z_t$ be temperature deviation (from 1900) in deep ocean. $F_t$ is exogenous radiative forcing (the imbalance between incoming and outgoing energy).

$$H_{t+1} = (1-a_0) H_t + a_1 \ln (M_{t+1}) + a_2 Z_t + F_{t+1} \tag{17}$$

$$Z_{t+1} = (1-a_3) Z_t + a_3 H_t \tag{18}$$

5. Physical output. $\omega_t Y_t$ are the resources spent on abatement. You also lose output when it gets hot–damage is $\xi H_t^2$. Net GDP is consumed or invested.

$$\omega_t = \psi_t \mu_t^\theta \tag{19}$$

$$C_t + I_t = \underbrace{\left(1 - \omega_t - \xi H_t^2\right)}_{\text{Damagd function}} Y_t \tag{20}$$

6. Utility. $C_t$ is per capita consumption.

$$W = \sum_{t=1}^{T} \frac{L_t U\left(C_t\right)}{\left(1+\rho\right)^t}$$

$$U\left(C\right) = \frac{C^{1-\alpha} - 1}{1-\alpha} \tag{21}$$

$$\alpha = 1.45 \tag{22}$$

The problem is to choose $C_t$ and $\mu_t$ to maximize social welfare.

7. Scenerios. Business as usual (BAU): evaluates $\mu_t$ at current policy. Alternative policies are to optimize welfare, or to choose $\mu_t$ and $C_t$ optimally to achieve certain targets,such as 2.5 degree maximum temperature by year 2100.

8. Social Cost of Carbon. The welfare cost of a marginal emission, in units of consumption.

$$\text{SCC} = \frac{\partial W_t}{\partial E_t} \frac{\partial C_t}{\partial W_t} = \frac{\partial C_t}{\partial E_t}$$

#### 5.0.1 Simplified DICE (SICE)

Ikefuji, Laeven, Magnus, and Muris claim that the following simplifications give the same result.

1. Replace the equations for $H$ and $Z$ with

$$H_{t+1} = \eta_0 + \eta_1 H_t + \eta_2 \ln\left(M_{t+1}\right)$$
$$\eta_0 = -2.872$$
$$\eta_1 = 0.8954$$
$$\eta_2 = 0.4622$$

2. Replace the three equations for atmospheric concentrations with

$$M_{t+1} = \phi M_t + E_t$$
$$\phi = 0.9942$$

3. Use this for the damage function

$$\frac{1-\omega_t}{1+\zeta H_t^2}, \ \zeta = 0.00265$$

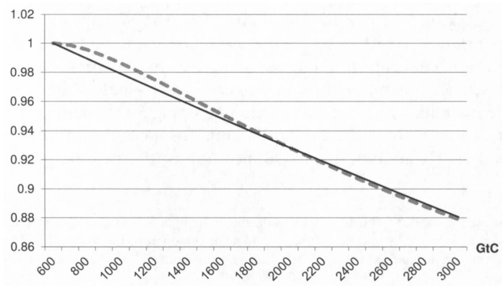


FIGURE 1.—Net-of-damages function $1 - D(T(S))$; Nordhaus (dashed) and exponential (solid).

Note: 600 GtC is pre-industrial level. 3,000 GtC is when most of predicted stocks of fossil fuel are burned.

4. (from Golosov et al.) When calibrating the damage function, Nordhaus (2008) used a bottom-up approach by collecting a large number of studies on various effects global warming. Some of these are positive (i.e., warming is beneficial). But adding these estimates up, he arrived at an estimate that a $2.5^oC$ heating yields a global (output-weighted) loss of 0.48% Also, he argued based on survey evidence, that with a probability of 6.8%, damage from $6^oC$ heating are catastrophic a loss of 30% of GDP. Nordhaus, calculates the willingness to pay for such a risk and added it to the damage function.

## 5.1 What DICE says

This is from "Revisiting the social cost of carbon," Nordhaus (2017), PNAS article.

"The most important single economic concept in the economics of climate change is the social cost of carbon (SCC). At present, regulations with more than $1 trillion of benefits have been written for the United States that use the SCC in their economic analysis. The DICE model (Dynamic Integrated model of Climate and the Economy) is one of three integrated assessment models used to estimate the SCC in the United States. The present study presents updated estimates based on a revised DICE model (DICE-2016R). The study estimates that the SCC is $31 per ton of CO2 in 2010 USD for the current period (2015). This study will be an important step in developing the next generation of estimates of the SCC in the United States and other countries."

Notes: (1) OLG: Changing fertility decisions, changing how one generation feels about the next. (2) Multiple decision makers. (3) Uncertainty.

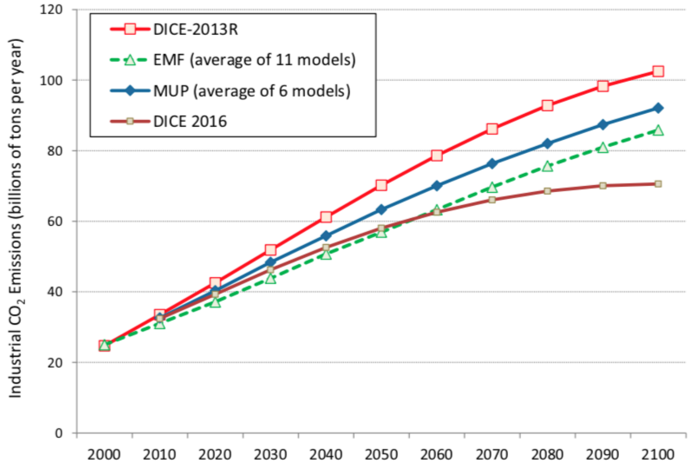


**Fig. 1.** Projected industrial $CO_2$ emissions in baseline scenario. The figure compares the projections of the most recent DICE models and two model comparison exercises. The estimates from the MUP project are from ref. 5, and the EMF-22 estimates are from ref. 14.

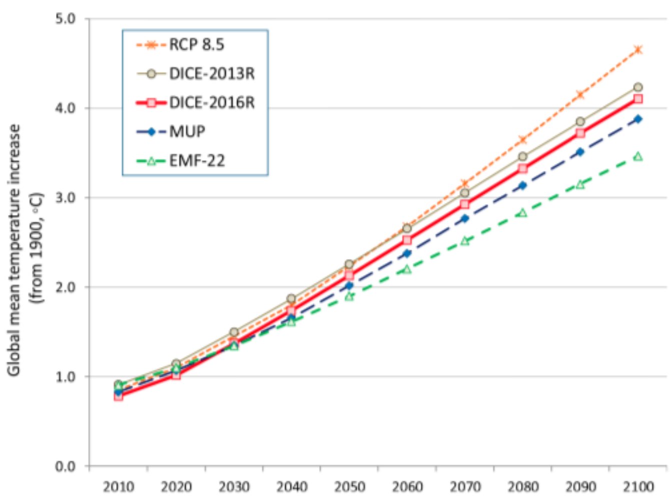


**Fig. 2.** Global mean temperature increase as projected by IPCC scenarios and integrated assessment economic models. The figure compares the projections of the most recent DICE models, the IPCC RCP high scenario (RCP 8.5), and two model comparison exercises.

The Social Cost of Carbon from DICE

**Table 1. Global SCC by different assumptions**

| Scenario | Assumption | 2015 | 2020 | 2025 | 2030 | 2050 |
|---|---|---|---|---|---|---|
| Base parameters | | | | | | |
| | Baseline* | 31.2 | 37.3 | 44.0 | 51.6 | 102.5 |
| | Optimal controls† | 30.7 | 36.7 | 43.5 | 51.2 | 103.6 |
| 2.5 degree maximum | | | | | | |
| | Maximum† | 184.4 | 229.1 | 284.1 | 351.0 | 1,006.2 |
| | Max for 100 y† | 106.7 | 133.1 | 165.1 | 203.7 | 543.3 |
| *The Stern Review* discounting | | | | | | |
| | Uncalibrated† | 197.4 | 266.5 | 324.6 | 376.2 | 629.2 |
| Alternative discount rates* | | | | | | |
| | 2.5% | 128.5 | 140.0 | 152.0 | 164.6 | 235.7 |
| | 3% | 79.1 | 87.3 | 95.9 | 104.9 | 156.6 |
| | 4% | 36.3 | 40.9 | 45.8 | 51.1 | 81.7 |
| | 5% | 19.7 | 22.6 | 25.7 | 29.1 | 49.2 |

The SCC is measured in 2010 international US dollars.
*Calculation along the reference path with current policy.
†Calculation along the optimized emissions path.