INTEGRATED ASSESSMENT MODELS

humberto.llavador@upf.edu

Introduction

- Integrated Assessment Models (IAMs)
  approaches that integrate knowledge from two or more domains into a single framework

  Economic Model + Geophysical Climate Model

- General Equilibrium
- Computerized simulations
- Literature more focused on results and applications: finding the cost of emissions (social cost of carbon)

humberto.llavador@upf.edu

INTRODUCTION

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- Origin in the energy models of 1970s and 1980s

Energy model + emissions and partial equilibrium

⇩

Energy system in a growth model and GE

- Nordhaus and Tobin (1972) “Is Growth Obsolete?”
- Nordhaus (1974) “Resources as a constraint for growth”

Greenhouse effect a much serious problem than scarcity of resources

Nordhaus (1980) first optimizing IAM - damage function

humberto.llavador@upf.edu

Introduction

"The point emphasized in IAMs is that we need to have *at a first level of approximation* models that operate all the modules simultaneously."

Nordhaus (2013:1077)

Very long list, and growing
(there's even an IAM Consortium -webpage-)

Among them:

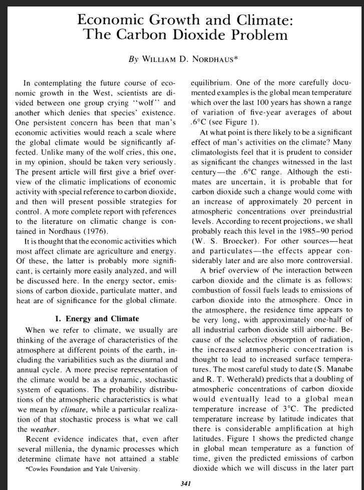
- DICE/RICE - Nordhaus
- FUND - Richard Tol
- PAGE - Chris Hope (Stern Review)
- Others: MERGE, GRACE,…

humberto.llavador@upf.edu

DICE/RICE IN CONTEXT

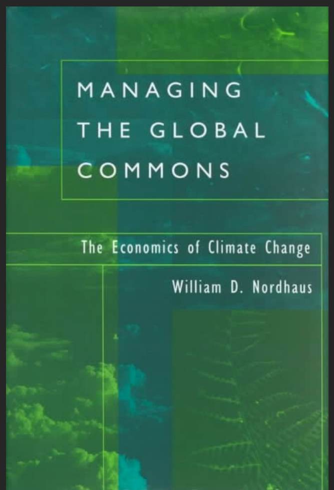
DICE-2016

ECONOMIC GROWTH AND CLIMATE (AER)

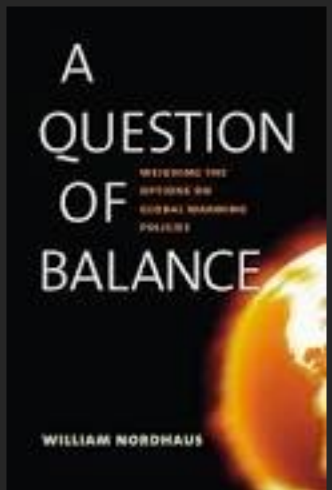

Economic Growth and Climate: The Carbon Dioxide Problem

By William D. Nordhaus*

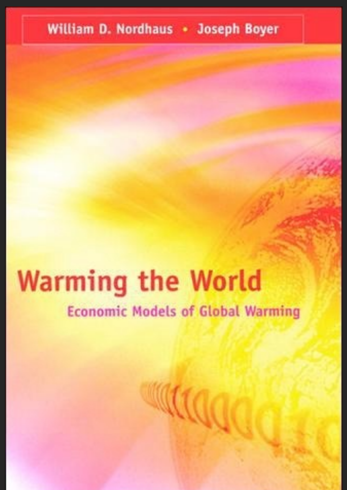
DICE-1994



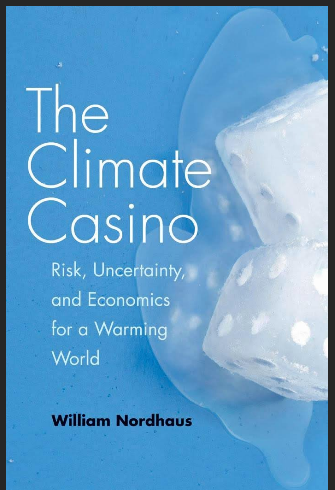
DICE-2008



RICE-2010



DICE-2013



1977

1994

2008

2010

2015

1990

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

1988

JAMES HANSEN ET AL.
NASA | MIT

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. D8, PAGES 9341–9364, AUGUST 20, 1988

Global Climate Changes as Forecast by Goddard Institute for Space Studies Three-Dimensional Model

humberto.llavador@upf.edu

DICE

Dynamic Integrated model of Climate and the Economy

humberto.llavador@upf.edu

DICE

Latest versions (in GAMS code)

- DICE2016R2 in Nordhaus (2018, AEJ: Economic Policy)
- DICE2016R3 in Nordhaus (2019, AER)
- An Excel version DICE-2016R (derived from the GAMS version)

- User's Manual. Nordhaus and Sztorc (2013)
- Evolution in Nordhaus (2018, Climatic Change): DICE1992-2017
- Forthcoming DICE-2022

humberto.llavador@upf.edu

DICE

1. Objective functions - representative agent
2. Economic sectors
3. Geophysical sectors

Neoclassical growth model
(Ramsey-Koopmans) incorporating
an environmental process.

humberto.llavador@upf.edu

DICE

A Objective: discounted sum of utilities

$$W = \sum_{t=1}^{T_{max}} R(t)V[C(t), L(t)] = \sum_{t=1}^{T_{max}} R(t)U[c(t)]L(t)$$

1. Constant elasticity utility function: $U[c(t)] = \frac{c(t)^{1-\eta}}{1-\eta}$

   η = elasticity of the marginal utility of consumption

   $\eta \to 0$: consumption between generations are close substitutes

   $\eta \to \infty$: close complements

$$\eta = 1: U[c(t)] = \ln c(t)$$

2. $R(t) = \frac{1}{(1+\rho)^t}$ discount factor (ρ = discount rate) represents the pure time preference.

humberto.llavador@upf.edu

B Economic sectors

Standard neoclassical decisions about capital accumulation and production

- Initial endowments of capital and labor: L_0 and K_0
- Exogenous population and technological change (TFP) growth

$$L(t) = [1 + g_L(t)]L(t-1), \text{ where } g_L(t) = \frac{g_L(t-1)}{1+\delta_L}$$

$$A(t) = [1 + g_A(t)]A(t-1), \text{ where } g_A(t) = \frac{g_A(t-1)}{1+\delta_A}$$

Population and TFP growth decline over time.

humberto.llavador@upf.edu

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B Economic sectors: production function

Cobb-Douglas production function

- Gross output (in the absence of damages and abatement)

$$Y(t) = A(t)K(t)^{\gamma}L(t)^{1-\gamma}$$

TFP: $A(t) = [1 + g_A(t)]A(t-1)$, where $g_A(t) = \frac{g_A(t-1)}{1+\delta_A}$

- Climate damages (as fraction of gross output): $1 - \Omega(t)$
- Net output (net of climate damages)

$$\Omega(t)A(t)K(t)^{\gamma}L(t)^{1-\gamma}$$

- Abatement costs (fraction of net output devoted to abatement): $\Lambda(t)$
- Output net of damages and abatement

$$Q(t) = (1 - \Lambda(t))\Omega(t)A(t)K(t)^{\gamma}L(t)^{1-\gamma}$$

humberto.llavador@upf.edu

DICE

B Economic sectors. $Q(t) = (1 - \Lambda(t))\Omega(t)A(t)K(t)^{\gamma}L(t)^{1-\gamma}$

Damage function $\Omega(t) = 1 - D(t)$

$$D(t) = \Psi_1 T(t) + \Psi_2 T(t)^2$$

Abatement costs $\Lambda(t) = \theta_1(t)\mu(t)^{\theta_2}$

Policy: emission abatement rate

Highly convex ($\theta > 2$).
Calibrated so that the marginal cost of abatement equals the cost of an exogenous backstop technology at 100%

 humberto.llavador@upf.edu

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B Economic sectors

Market clearing

$$Q(t) = C(t) + I(t)$$

$$Y(t) - damages(t) = C(t) + I(t) + Abatement(t)$$

Capital accumulation

$$K(t) = I(t) + \delta_k K(t-1)$$

Emissions are proportional to output

Policy

$$E(t) = E_{Ind}(t) + E_{Land}(t) = \sigma(t)(1 - \mu(t))Y(t) + E_{Land}(t)$$

Carbon intensity
(exogenous and declines over time)

$$CCum \geq \sum_t E_{Ind}(t)$$ Limit of total fossil fuel resources

humberto.llavador@upf.edu

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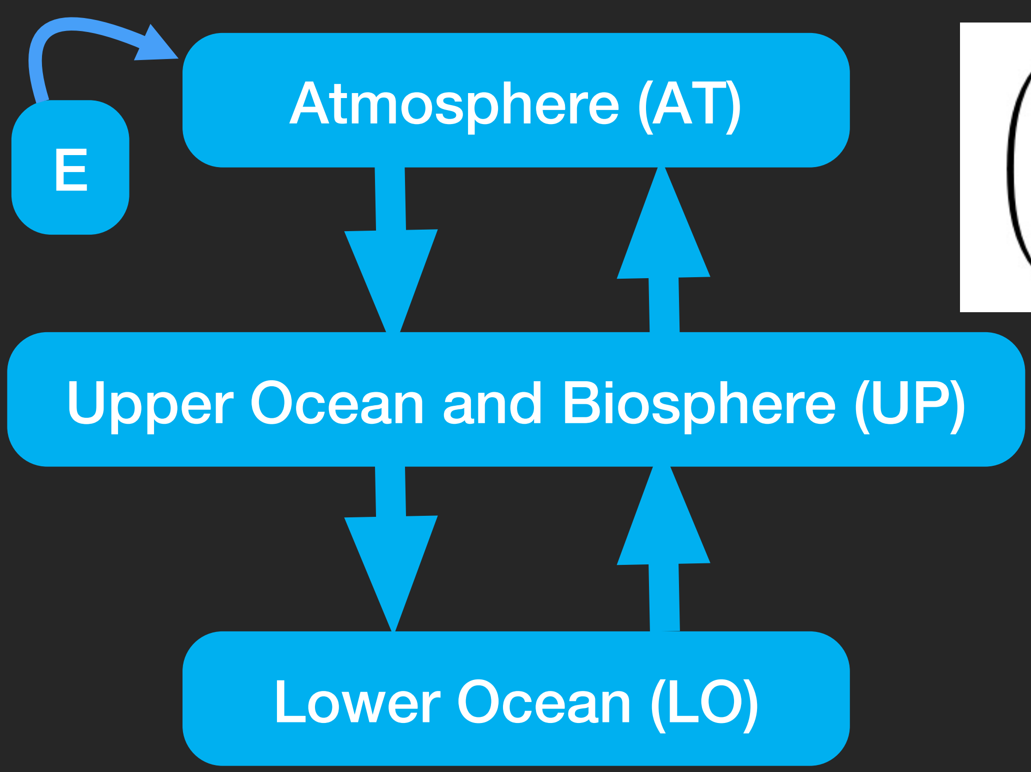
C. Geophysical sector

I. Carbon cycle — emissions → carbon concentration

II. Radiative Forcing — warming impact

III. Temperature change — radiative forcing → temperature increase

I. Carbon Cycle: 3-reservoirs, linear system (Matrix representation in Machta, 1972)



$$\begin{pmatrix} M_{AT,t} \\ M_{UP,t} \\ M_{LO,t} \end{pmatrix} = \begin{pmatrix} \phi_{11} & \phi_{21} & 0 \\ \phi_{12} & \phi_{22} & \phi_{32} \\ 0 & \phi_{23} & \phi_{33} \end{pmatrix} \begin{pmatrix} M_{AT,t-1} \\ M_{UP,t-1} \\ M_{LO,t-1} \end{pmatrix} + \begin{pmatrix} E_t + E_t^{Land} \\ 0 \\ 0 \end{pmatrix}$$

humberto.llavador@upf.edu

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C. Geophysical sector

I. Carbon cycle — emissions → carbon concentration
II. Radiative Forcing — warming impact
III. Temperature change — radiative forcing → temperature increase

II. **Radiative forcing:** observed relationship

$$F(t) = \eta \log_2 \frac{M_{AT}(t)}{M_{1750}} + F_{EX}(t)$$

Change in total forcing from atmospheric sources

Forcing from atmospheric concentration of CO2

Exogenous forcing

Climate sensitivity parameter: increase in forcing/temperature from doubling the stock of CO_2

humberto.llavador@upf.edu

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C. Geophysical sector

I. Carbon cycle — emissions → carbon concentration
II. Radiative Forcing — warming impact
III. Temperature change — radiative forcing → temperature increase

III. **Temperature change** (warming), determining climate change damages

Higher radiative forcing warms the atmospheric layer, which then warms the upper ocean, gradually warming the deep ocean. The lags in the system are primarily due to the diffusive inertia of the different layers.

$$T_{AT}(t) = T_{AT}(t-1) + \{\xi_1[F(t) - \xi_2 T_{AT}(t-1) - \xi_3[T_{AT}(t-1) - T_{LO}(t-1)]]\}$$

$$T_{LO}(t) = T_{LO}(t-1) + \xi_4[T_{AT}(t-1) - T_{LO}(t-1)]$$

Climate change damages

$$D(t) = \Psi_1 T_{AT}(t) + \Psi_2[T_{AT}(t)]^2$$

humberto.llavador@upf.edu

Summary

$$\max W := \sum_{t=1}^{T} \beta^t L(t) \log c(t)$$

s.t.

Objective: Discounted sum of utilities

$$\left[1-\Lambda(t)\right]\Omega(T(t))Y\left[K(t),L(t)\right]=C(t)+I(t)$$

Abatement Damages Cobb-Douglas Production

$$E(t)=\sigma(t)\,Y\left[K(t),L(t)\right]$$

Carbon intensity

Economic growth model

Radiative force

$M_{AT}(t)$ Atmosphere

$M_{UP}(t)$ Surface

$M_{LO}(t)$ Deep ocean

Climate Model

Carbon concentration

humberto.llavador@upf.edu

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Results

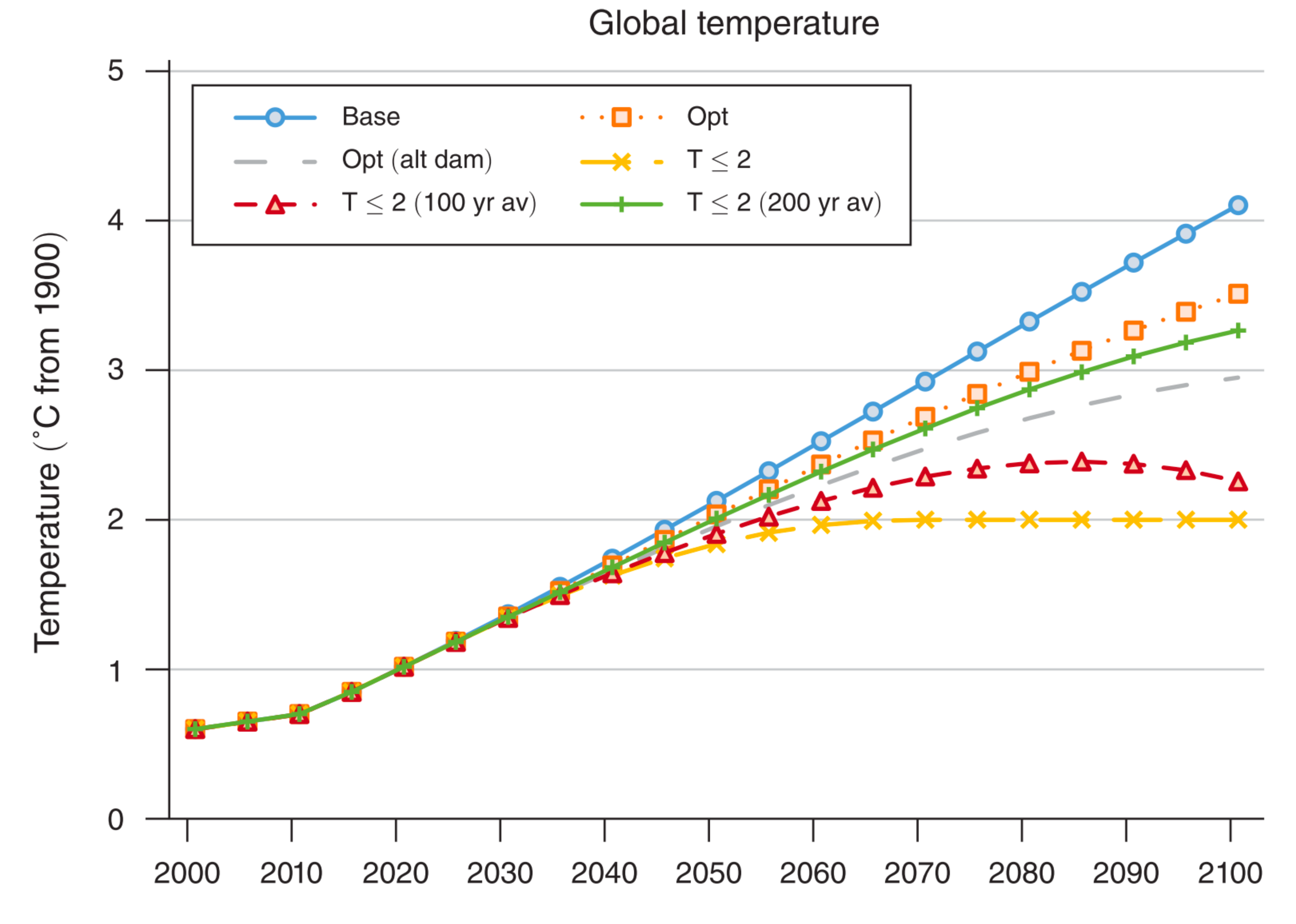

Figure 5. Temperature Trajectories for Different Objectives

DICE-2016R3
Nordhaus (2019)

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Results

TABLE 1—SOCIAL COST OF CARBON ALTERNATIVE CONCEPTS, DICE 2016-R3 MODEL (2018$)

	Social cost of carbon 2018$ per ton of CO_2			
	2015	2020	2050	2100
Base	37	45	108	304
Optimal	36	43	105	295
Optimal (alt dam)	91	108	249	584
$T \leq 2.5$ (200yr)	41	49	123	379
$T \leq 2.0$ (200yr)	49	59	153	511
$T \leq 1.5$ (200yr)	69	84	226	776
$T \leq 2.5$ (100yr)	76	93	260	755
$T \leq 2.0$ (100yr)	130	158	413	1,013
$T \leq 1.5$ (100yr)	236	279	682	1,191
$T \leq 2.5$	95	118	361	477
$T \leq 2.0$	225	275	749	459
$T \leq 1.5$	NF	NF	NF	NF

Notes: Base = no controls. *Optimal* = cost-benefit maximum with base and alternative damage function. $T \leq 2.5$ (200yr) = temperature limited 2.5°C for a 200-year average (and the parallel notation for different temperature limits and averaging periods). $T \leq 2.5$ is temperature limited to 2.5°C as a hard constraint. In the table, "NF" indicates not feasible.

DICE-2016R3
Nordhaus (2019)

humberto.llavador@upf.edu

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Results

Estimations have become more drastic over time

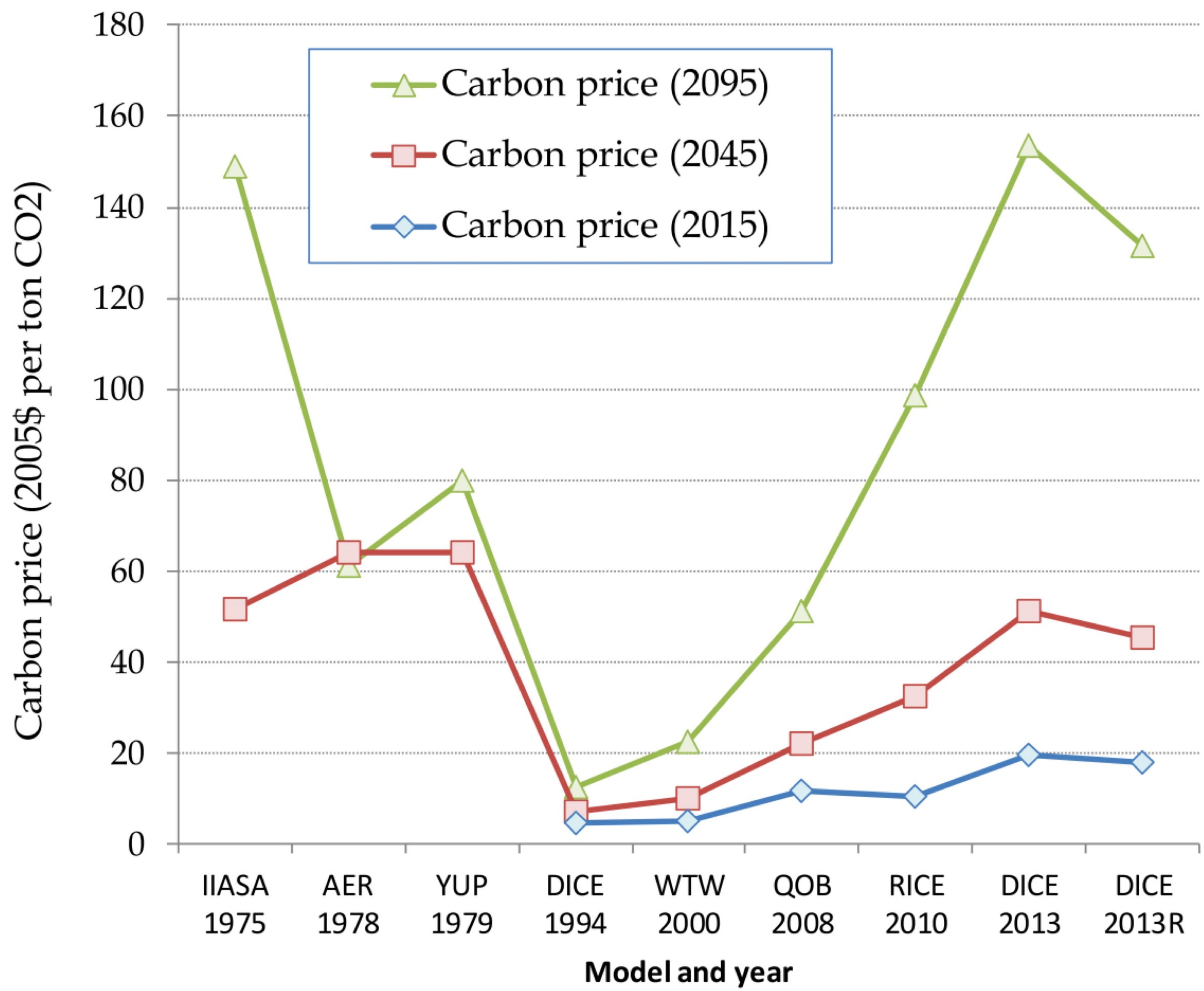

Figure 15. Optimal carbon price, different vintages DICE/RICE models, 2005 \$ per ton CO_2 . Prices are for the indicated years.

The Relevance of the Discount Rate: Nordhaus vs. Stern

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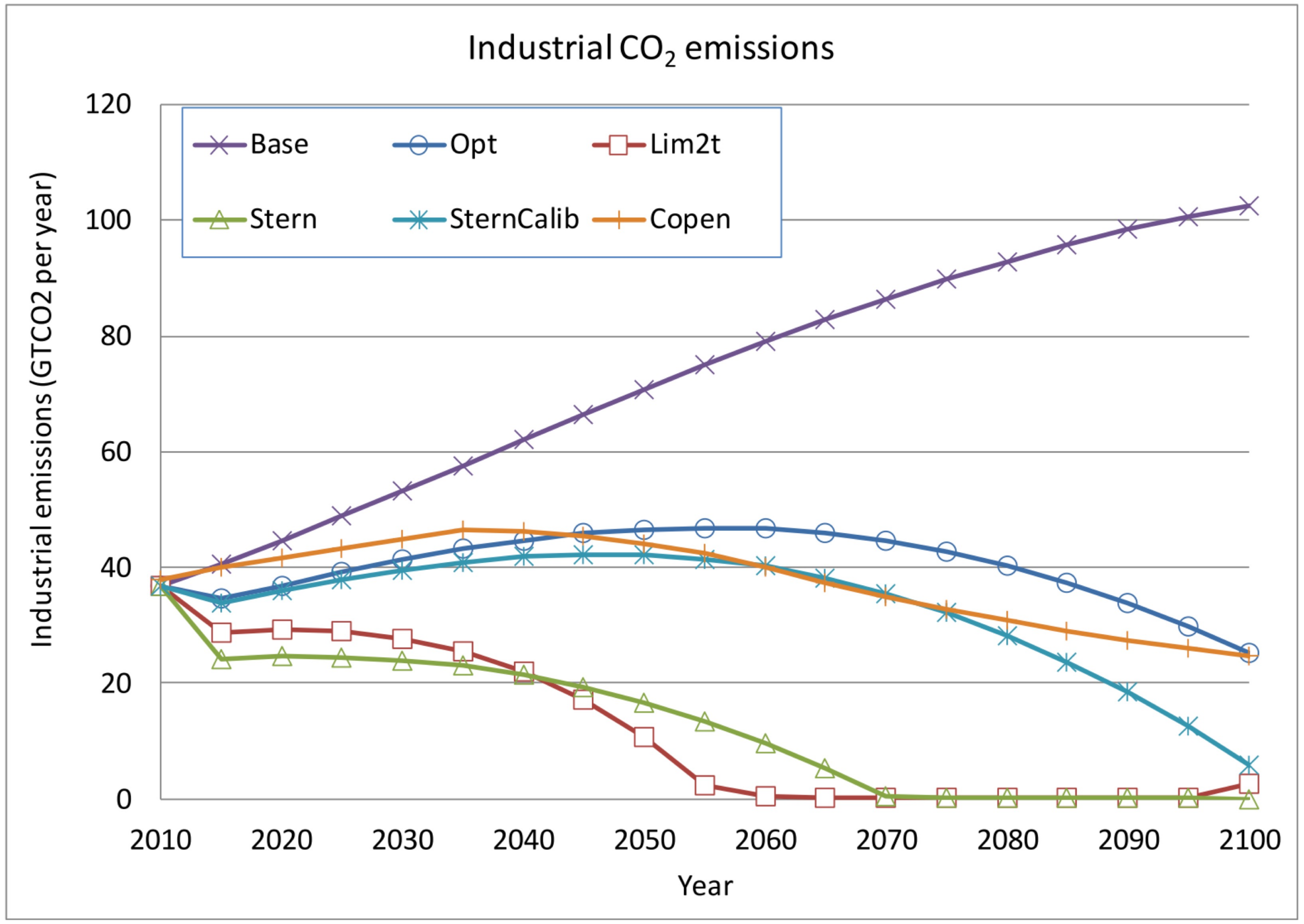

Figure 6. Projected emissions of CO_2 under alternative policies, DICE-2013R model

Nordhaus: 1,5% annual → 100 years → 22%

Stern: 0,1% annual → 100 years → 90%

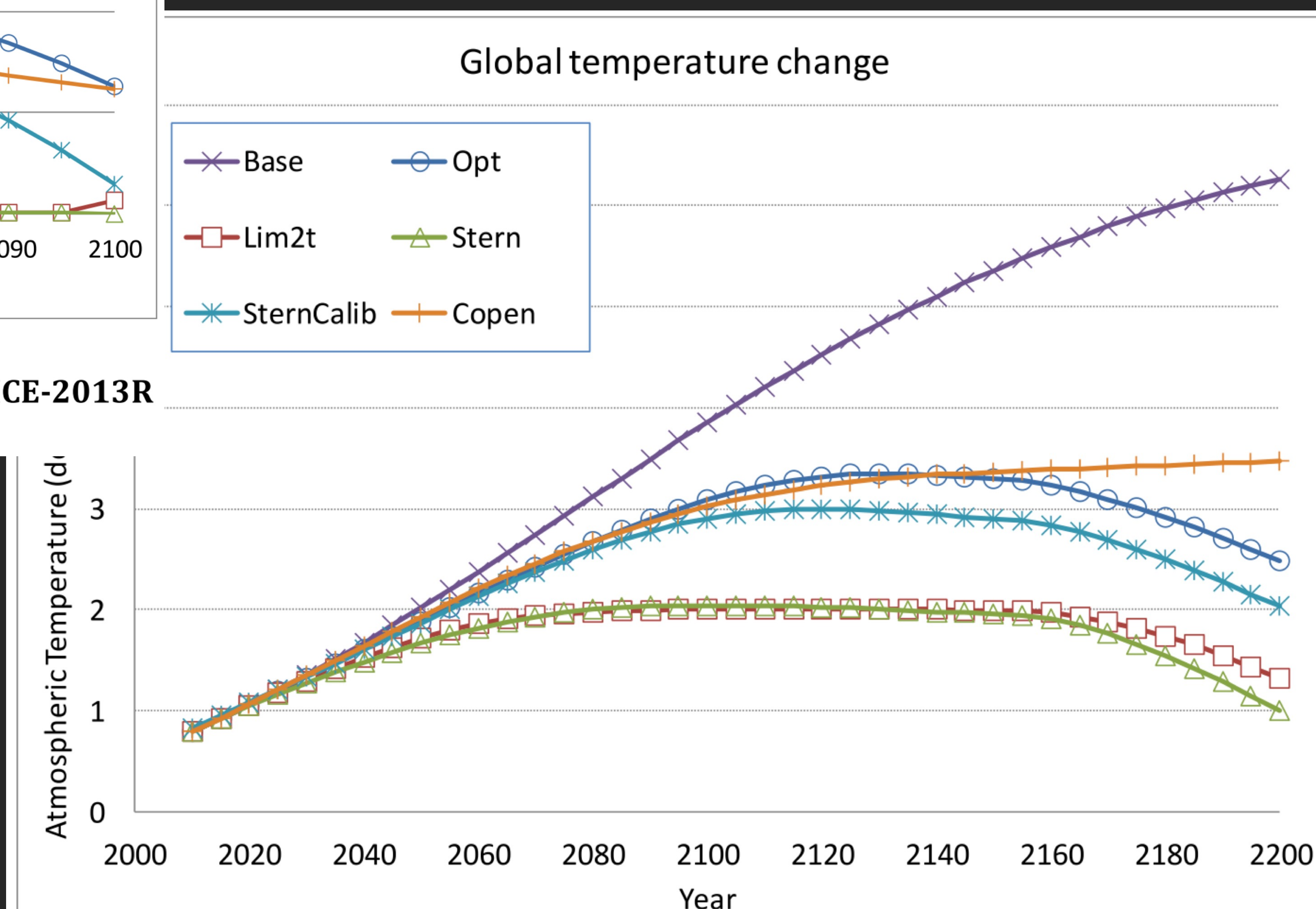

Figure 8. Global temperature increase (°C from 1900) under alternative policies, DICE-2013R model

humberto.llavador@upf.edu

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humberto.llavador@upf.edu