The economics of climate change

C 175 - Christian Traeger

Part 6: Integrated Assessment

Background/Further reading:

Nordhaus, W. D. & J. Boyer (2000), Warming the World, MIT Press.

Stern, N. (2007), The Economics of Climate Change, Cambridge University Press.

Nordhaus, W.D. (2008), A Question of Balance - Weighing the Options on Global Warming Policies, Yale University Press.

What is an Integrated Assessment?

So far we have analyzed

- The **science of climate change** addressing the relation between GHG emissions, temperature and climate change, and their impacts
- the **economics** of **policies** addressing GHG emissions

Now we combine the two aspects!

An **integrated assessment model (IAM) combines** scientific and socio-economic aspects of climate change for the purpose of assessing impacts and policies.

Why an Integrated Assessment Model?

Why is such a combined model useful for assessing climate change?

Because

- GHG emissions affect climate change
- Climate change affects economic production and welfare
- Economic production and welfare affect GHG emissions

-> continuous interaction between the economy, welfare, and climate system

A policy that changes one of the above aspects changes all aspects and how they develop influence each other over time!

Components of an Integrated CC Assessment

Mitigation Policy

Population, technology, production, consumption

Emissions

Atmospheric concentrations

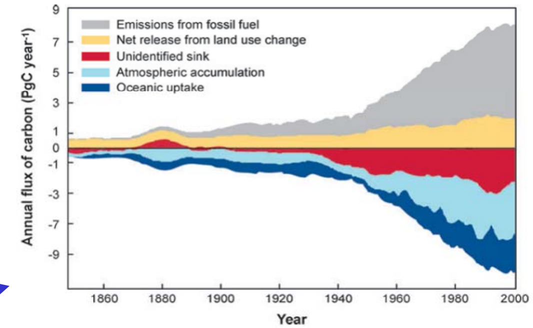
Radiative forcing

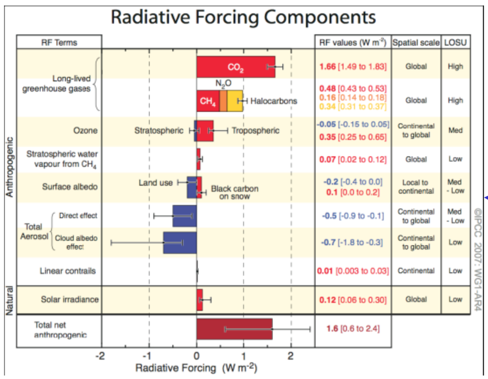
Temperature rise and global climate change

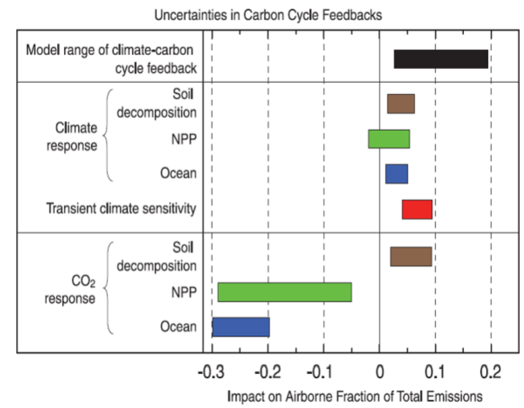
Direct impacts (e.g. crops, forests, ecosystems)

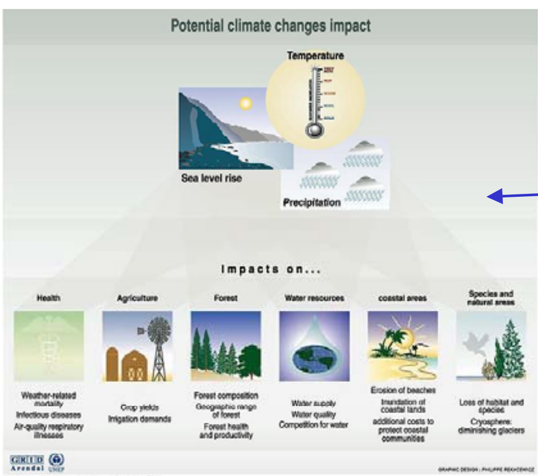
Socio-economic impacts

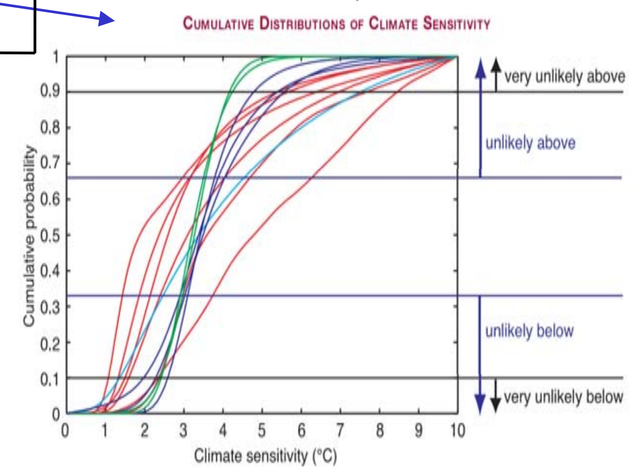
Feedbacks











A Prototype of an IAM: DICE

Building Blocks of an Integrated Assessment Model

We introduce a slightly simplified version of a stylized IAM:

Nordhaus' widespread *DICE model*

- We analyze the most important equations determining
  - Production, Investment, and Emissions
- And equations describing how
  - Capital
  - GHG concentrations
  - Temperatures

  evolve over time (stocks!)
- Finally, a welfare function is to be maximized adhering to these equations

Building Blocks of IAMs: Production

- Production: In period t output is

$$Y_t = \frac{1 - \Lambda_t}{D_t} A_t K_t^{\gamma} L_t^{1-\gamma}$$

which is made up of

  - Cobb Douglas production function with inputs
    - Capital K_t
    - Labor L_t
  - Technological Progress A_t (increases over time)
  - Damage D_t reduces output
  - Costs incurred for reducing emissions Λ_t
    (emissions coming up later)

Building Blocks of IAMs: Production

$$Y_t = \frac{1 - \Lambda_t}{D_t} A_t K_t^{\gamma} L_t^{1-\gamma}$$

How do we get the values (in DICE)?

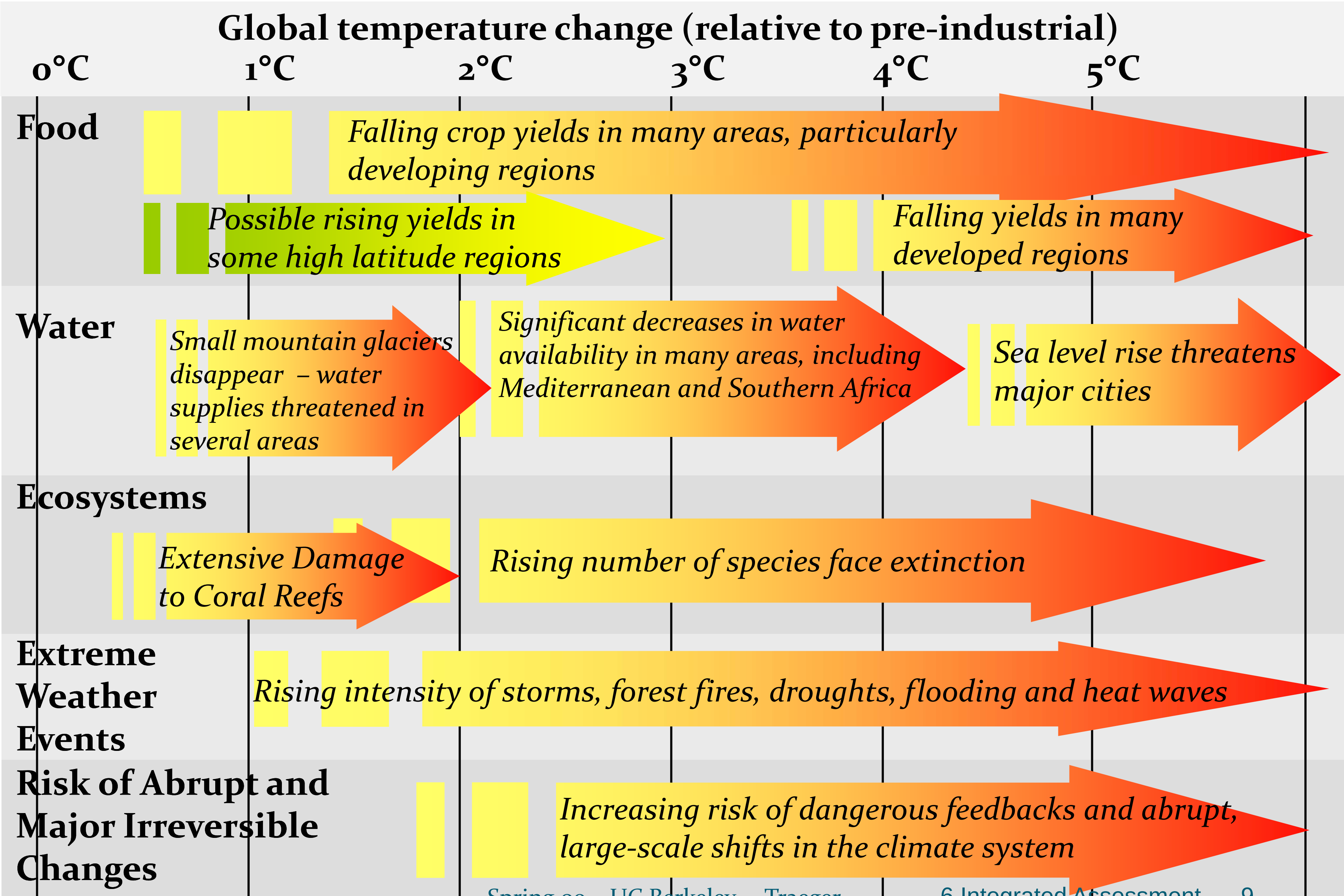
- Labor $\boldsymbol{L_t}$ is *exogenous* estimate taken from population models
- Capital $\boldsymbol{K_t}$ is calculated as part of the model (-> *endogenous*) (next building block)
- Parameter $\boldsymbol{\gamma}$ is estimated $\boldsymbol{\gamma=.3}$
- Technological Progress $\boldsymbol{A_t}$ is *exogenous* 'estimate'
- Damage $\boldsymbol{D_t}$ is approximated as a quadratic function of temperature :

$$D_t = a_0 + a_1 T_t + a_2 T_t^2$$

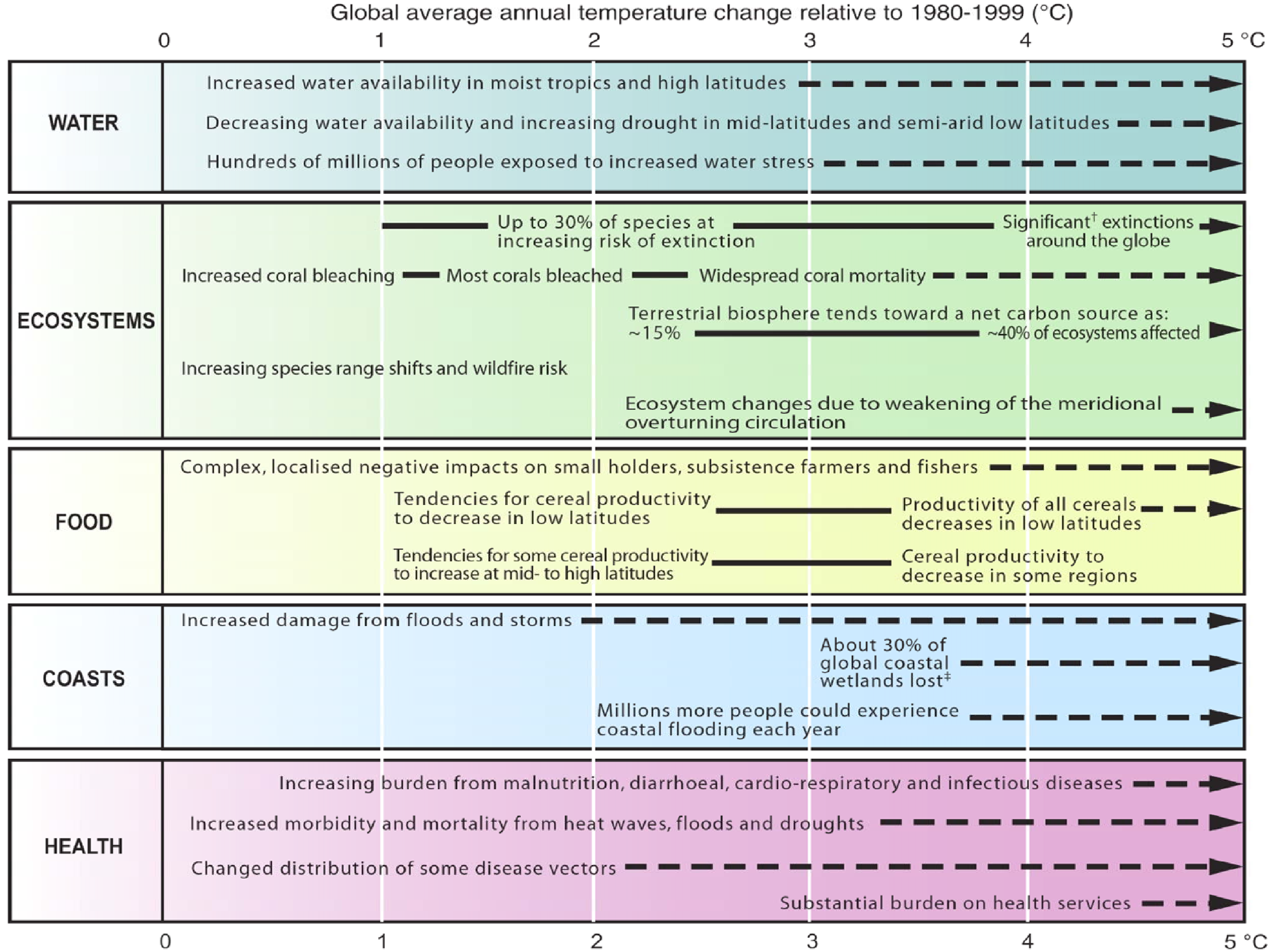
Note: Thus, modeling precipitation change or sea level rise is cut out in the model and adverse effects are directly related to temperature change

- Costs of emission reduction is estimated as a function $\boldsymbol{\Lambda_t (\mu_t)}$ of the emission-control rate $\boldsymbol{\mu_t}$ (percentage of emissions mitigated, emissions coming up later)

IAMs: on Damages... (Stern Review)



IAMs: on Damages… (IPCC AR4)



Sources: IPCC (2008)

Regional damage estimates in DICE-2007

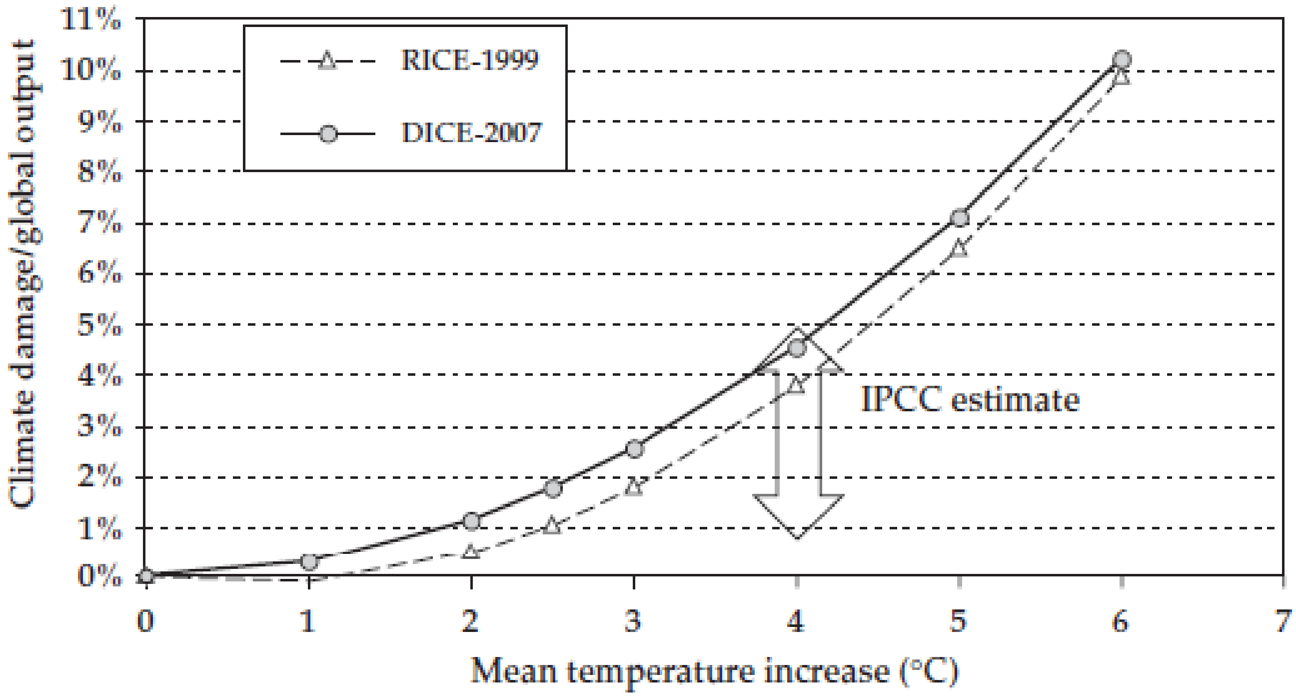
Regional damage estimates for 2005 and temperature increase of 2.5°C

Region	Agriculture	Other vul- nerable mkt	Coastal	Health	market time use	Settlements	Catastrophi [2.5 degree]	c
US	0.03%	0.00%	0.10%	0.02%	-0.28%	0.10%	0.94%	
WE/Euro	0.03%	0.00%	0.46%	0.02%	-0.43%	0.25%	1.09%	
OHI	-0.05%	-0.32%	0.09%	0.02%	-0.35%	0.10%	1.11%	
Russia	-0.82%	-0.80%	0.05%	0.02%	-0.75%	0.05%	1.12%	
EE/FSU	0.03%	0.00%	0.01%	0.02%	-0.36%	0.10%	0.94%	
Japan	0.02%	0.00%	0.27%	0.02%	-0.31%	0.25%	1.07%	
China	0.02%	0.32%	0.08%	0.09%	-0.26%	0.05%	1.04%	
India	0.32%	0.29%	0.09%	0.40%	0.30%	0.10%	1.57%	
MidEast	0.35%	0.20%	0.04%	0.23%	0.24%	0.05%	0.96%	
SSA	0.67%	0.32%	0.02%	1.00%	0.25%	0.10%	1.78%	
LA	0.42%	0.28%	0.10%	0.32%	-0.04%	0.10%	1.30%	
OthAsia	0.52%	0.21%	0.09%	0.32%	-0.04%	0.10%	1.23%	

Uses individual indices relating temperature/climate change to damage for the different dimensions of damage (columns).

Aggregate Damage Estimates DICE-2007

- Adding estimates for catastrophic damages and
- Aggregating over Regions and
- Extrapolating for temperature changes other then 2.5°C yields Damage



Source: Nordhaus (2007), Figure 3-3, Damage function in DICE-2007 versus earlier model (RICE-1999) and estimated range from IPCC AR4, which reports that "global mean losses could be 1–5% GDP for 4°C of warming".

Building Blocks of IAMs: Capital

- Production uses capital which is accumulated over time:
  - In the present capital can be measured (K_0),
  - If capital (stock!) is K_t in the period t then in period $t+1$ it is

$$K_{t+1} = (1 - \delta_k) K_t + I_t$$

  - a fraction δ_k of the capital depreciates
  - I_t describes new investment into capital

$$I_t = Y_t - C_t$$

  - Everything produced but not consumed is invested

Building Blocks of IAMs: Emissions

- Emissions from production in period ***t*** (flow):

$$E_t = \sigma_t (1-\mu_t) A_t K_t^{\gamma} L_t^{1-\gamma}$$

  - $\boldsymbol{\sigma_t}$: ratio of uncontrolled industrial emissions to output (metric tons of carbon per output, 'carbon-intensity of output')
  - $\boldsymbol{\mu_t}$: emissions-control rate (fraction mitigated at cost $\Lambda_t(\mu_t)$)
- Emissions from land use change and forestry in period ***t*** (flow):

  $LUCF_t$ taken as *exogenous*

- Stock of emissions in period ***t+1***:

$$M_{t+1} = (1-\delta_M) M_t + E_t + LUCF_t$$

  - fraction $\boldsymbol{\delta_M}$ of emission stock naturally depleted (leaves the atmosphere)
- Note: Actual DICE also models carbon transfer to and in oceans

Building Blocks IAM: Temperature

- Temperature: In period ***t*** temperature increase w.r.t. preindustrial is

$$T_{t+1} = T_t + \sigma \left(F_t - \lambda T_t \right)$$

- Temperature increases proportional to the difference between
  - Radiative forcing $\boldsymbol{F_t}$ in period ***t***
  - The equilibrium forcing $\boldsymbol{\lambda T_t}$ that would correspond to $\boldsymbol{T_t}$
  - $\boldsymbol{\sigma}$ characterizes delay in temperature increase (small $\boldsymbol{\sigma}$ slow change)
- Radiative forcing $\boldsymbol{F_t}$ is given by

$$F_t = \eta \left(\frac{\ln\left(\frac{M_t}{M_{preind}}\right)}{\ln 2} \right) + OtherGHGs_t$$

With:

- $\boldsymbol{\eta}$ = forcing parameter
- $\boldsymbol{M_{preind}}$ = Preindustrial CO2 stock
- $\boldsymbol{OtherGHGs_t}$= non-CO2 GHGs

taken as exogenous

Building Blocks IAM: Welfare

- Temperature closes the model feeding back into the damage function

However, in order to distinguish a good situation from a bad one we need:

- Welfare function:

$$W = \sum_t \frac{1}{(1+\rho)^t} u(C_t, L_t)$$

with

- Pure rate of time preference $\boldsymbol{\rho}$
- $u(C_t, L_t) = L_t \frac{\left(\frac{C_t}{L_t}\right)^{1-\vartheta}}{1-\vartheta}$
- Consumption elasticity of marginal utility ϑ
- Per capita consumption $\frac{C_t}{L_t}$