Toward an Integrated Global MARKAL/TIMES Model

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Objective

- Use a regionalized Global Bottom-up model to conduct various equilibrium computations:
  - Cooperative GHG abatement
  - Non cooperative (Nash) abatemnt
  - General (informal) formulation:

Min (abatement cost + damage cost)

Why are damage costs needed?

- In the case of a cooperative equilibrium, one could rely on using a concentration target that is globally desirable (optimal), and then convert it to global emission constraints to be used in the MARKAL model.
- In the case of a non-cooperative equilibrium, the concentration resulting from the players actions is unknown, since each player has only its own total cost as an objective.

Non cooperative GHG abatement

- If global agreement on reductions may not be achieved via negotiations
- Each country (region) would then examine its own costs and benefits of abatement
- However, each country would also take into account the likely actions of other countries when making its own decisions
- The above leads to a Nash equilibrium

Nash equilibirum

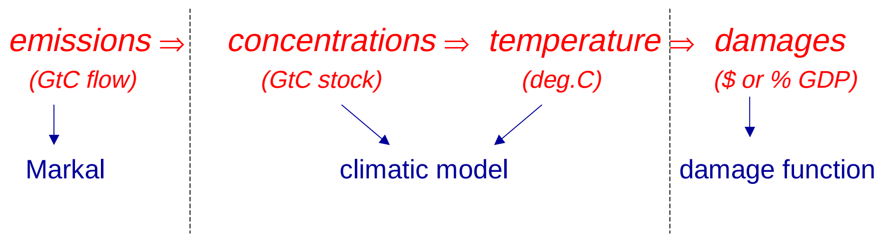
- Each region r chooses emissions e_r, so as to minimize its total cost:

$$\text{Abatement cost}_r + \text{Damage cost}_r$$

- where it is understood that damage cost depends on global emissions

Representation of damage costs

Causal chain :



Simplified climatic Model (Nordhaus, 1998)

Global emissions ⇒ Concentrations :

- simplified 3-reservoir model (atmosphere, ocean surface, deep ocean)

$$M_{atm}(t) = E(t) + \phi_{11} M_{atm}(t-1) - \phi_{12} M_{atm}(t-1) + \phi_{21} M_{up}(t-1)$$

$$M_{up}(t) = \phi_{22} M_{up}(t-1) + \phi_{12} M_{atm}(t-1) - \phi_{21} M_{up}(t-1) + \phi_{32} M_{lo}(t-1) - \phi_{23} M_{up}(t-1)$$

$$M_{lo}(t) = \phi_{33} M_{lo}(t-1) - \phi_{32} M_{lo}(t-1) + \phi_{23} M_{up}(t-1)$$

- $M_{at, up, lo}$ (GtC) CO_2 accumulated in atmosphere, in upper ocean layers, and in lower ocean layers respectively
- E (GtC) CO_2 emissions de

Φ_{ij}	transfer rate from reservoir i to reservoir j
M_{atm} (1990)	= 735 GtC
M_{up} (1990)	= 781 GtC
M_{lo} (1990)	= 19230 GtC
$M_{atm\ 0}$	= 590 GtC (pre-industrial equilibrium)

Simplified climatic Model (Nordhaus, 1998)

Concentrations ⇒ radiative forcing : $\Delta F(t) = \gamma * \{ \ln (M(t) / M_0) / \ln 2 \} + O(t)$

$\Delta F(t)$	radiative forcing relative to pre-industrial period (W/m^2)
γ	sensitivity of climate to doubling of CO2 concentration = 4.1 W/m^2
O(t)	radiative forcing of other GHG 's
O(t) =	-0.1965 + 0.013465 t if t < 100 years / 1.15 if t > 100 years

Radiative forcing and concentration ⇒ Temperature increase:

- simplified 2 reservoir model (atmosphere + ocean surface, deep ocean)

$$\Delta T_{up}(t) = \Delta T_{up}(t-1) + \sigma_1 \{\Delta F(t) - \lambda \Delta T_{up}(t-1) - \sigma_2 [\Delta T_{up}(t-1) - \Delta T_{low}(t-1)]\}$$

$$\Delta T_{low}(t) = \Delta T_{low}(t-1) + \sigma_3[\Delta T_{up}(t-1) - \Delta T_{low}(t-1)]$$

$\Delta T_{up, lo}$	Increase in temp of reservoir up and lo, relative to pre-industrial temperature
$\sigma_{1, 2, 3}$	thermal charactéristics of reservoirs
λ	climatic feedback parameter (= $4.1/C_s$ with C_s = sensitivity to doubling of concentration = 2.9 C)
ΔT_{up} (1990)	= 0.46 °C
ΔT_{low} (1990)	= 0.1 °C

Damage function (Nordhaus, 1998)

Temperature increase ⇒ Damages (region specific):

$$d(t) = a_1 * (\Delta T/a_3)^{a2} + a_4 * \Delta T$$

d(t)	damages at time t
ΔT	temperature increase at period t

Caveats

High degree of uncertainty on shape and parameters
Speed of temperature increase not taken into account
Adaptation to climate change?
Feedback of damages on MARKAL demands?

Approach A: full representation

- Augment MARKAL with the complete set of climatic equations and damage functions
- Drawbacks:
  - creation of many additional non-MARKAL constraints,
  - some are non linear, non convex

Approach B: simplification of damage function

Basic question: What error is made in assuming that damages depend only on total cumulative emissions, irrespective of the shape of emission trajectory?

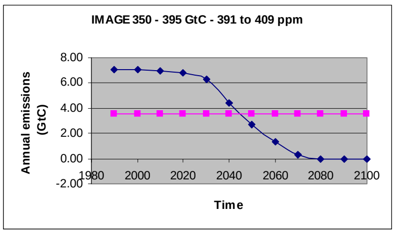
$\text{Damages}_r = f_r$ (global cumulative emissions) ?

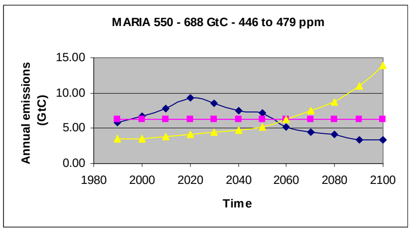
Empirical estimation of Damages = f (global cum. em.) ?

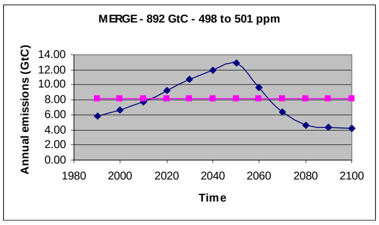
We used 21 emission trajectories (12 from literature, 9 artificial)

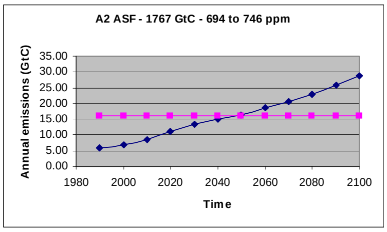
- Emissions Scenarios from IPCC ("SRES - Emissions scenarios") : A1-AIM, B1-IMAGE, A2-ASF, B2-MESSAGE
- Stabilisation Scenarios from IPCC ("Post-SRES") : IMAGE 350/450/650/750ppm, MARIA 550ppm, MERGE Stblz
- Other scenarios : RICE 2001, Émi cst 90
- Fictitious emission trajectories: e.g. Constant through time, increasing emissions

9 examples of emission trajectories



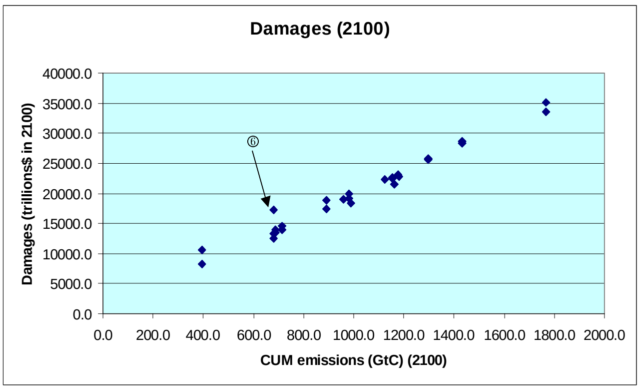






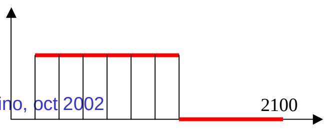
Blue : trajectory   Pink :fictitious trajectory fictive (constant)   Yellow: fictitious trajectory (increasing)

Global damages = f(global Cum Em.)

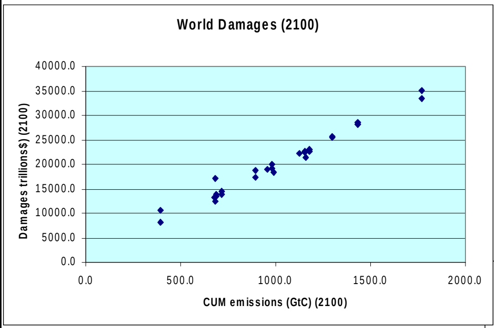


Equation : y=a+bx   a= 1406.8   b=18.5   S=1001   r=0.989

⑥ The outlier is an extreme emission trajectory where all emissions occur prior to 2060, and zero afterward



Effect of horizon: 2050 vs. 2100



Équation : y=a+bx
a= 1406.8 b=18.5
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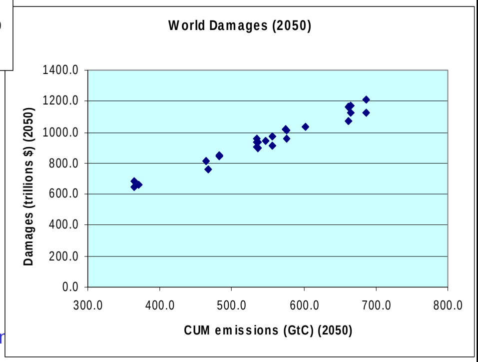


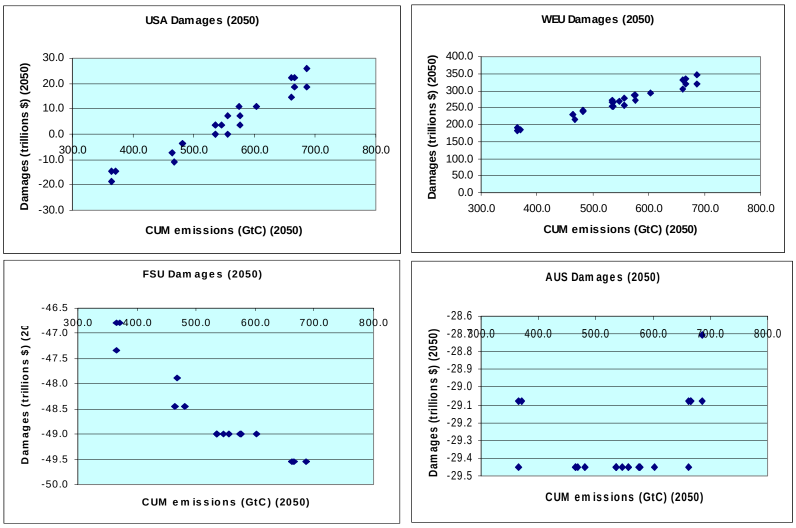
Équation : y=a+bx
a= 90.811 b=1.56
S=34.8 r=0.974

Conclusion on approach B

- Damage curve? : <u>Yes</u>, AND <u>Linear</u>

  - Approximation : Very good, especially in view of uncertainties on damage fonctions
  - Reason: late emissions have less time to be absorbed by ocean layers, but have also less time to provoke damages
  - Remark: The example treated here was for global damages. Similar functions are needed for each region r.

Regional damage curves (to 2050)



Part II: Computing abatement strategies with integrated model

Minimize {emission cost + damage cost)

- Two abatement strategies considered:

1. Cooperative abatement (global optimization)
2. Non cooperative abatement (N player game, Nash equilibrium)

Cooperative GHG abatement

$$\text{Min } \Sigma\ c_r xr + f_r(\Sigma e_r)$$
$$\text{s.t.} \quad A_r x_r \leq b_r \text{ , all r}$$
$$\text{+ trade constraints}$$

Non cooperative Nash abatement

- Step 0: compute a starting point (e.g. cooperative solution, or BAU solution):

  X_r^0 r=1,.. N

  E_r^0 r=1,.. N

  set r = 0

- Step 1: r = r+1

  Min $c_r X_r + f_r\ (e_r + \Sigma_{k \neq r}\ e_k\ )$

  $A_r X_r \leq f_r$

  opt solution: X_r^*, E_r^*

- Step 2: $X_r^0 := X_r^*$

  $E_r^0 := E_r^*$

  If solution is stabilized for all r: STOP

  Else, Go to step 1