Integrated Assessment Modeling and Climate Agreements

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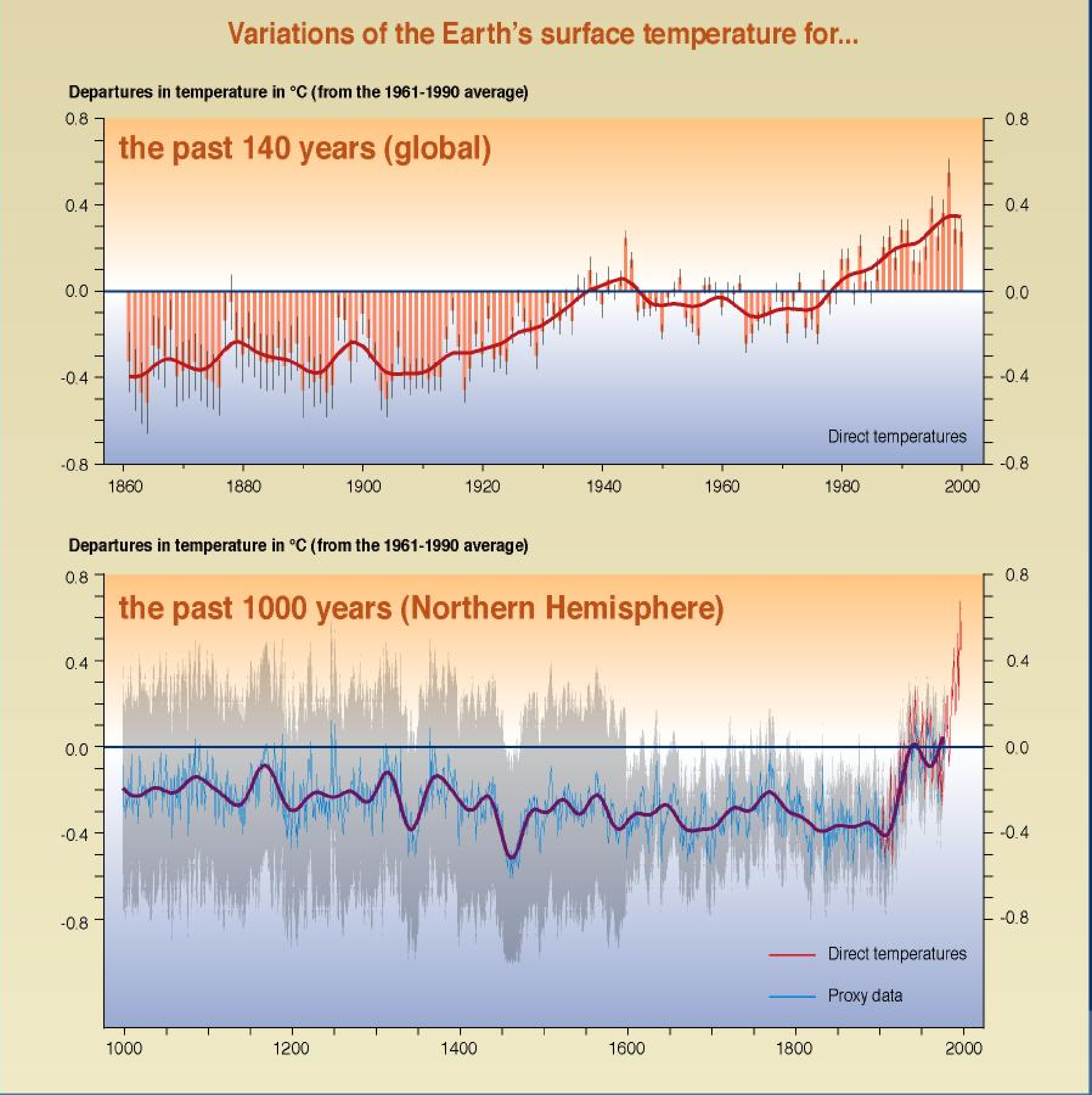
Outline

1. Introduction: the climate issue (in short)
2. The ClimNeg World Simulation (CWS) model
3. Three benchmark scenarios
4. Some cooperative and non cooperative game theory concepts
5. Analysis of potential climate agreements

1. The climate, in short

As an economic problem, climate change has the following characteristics:

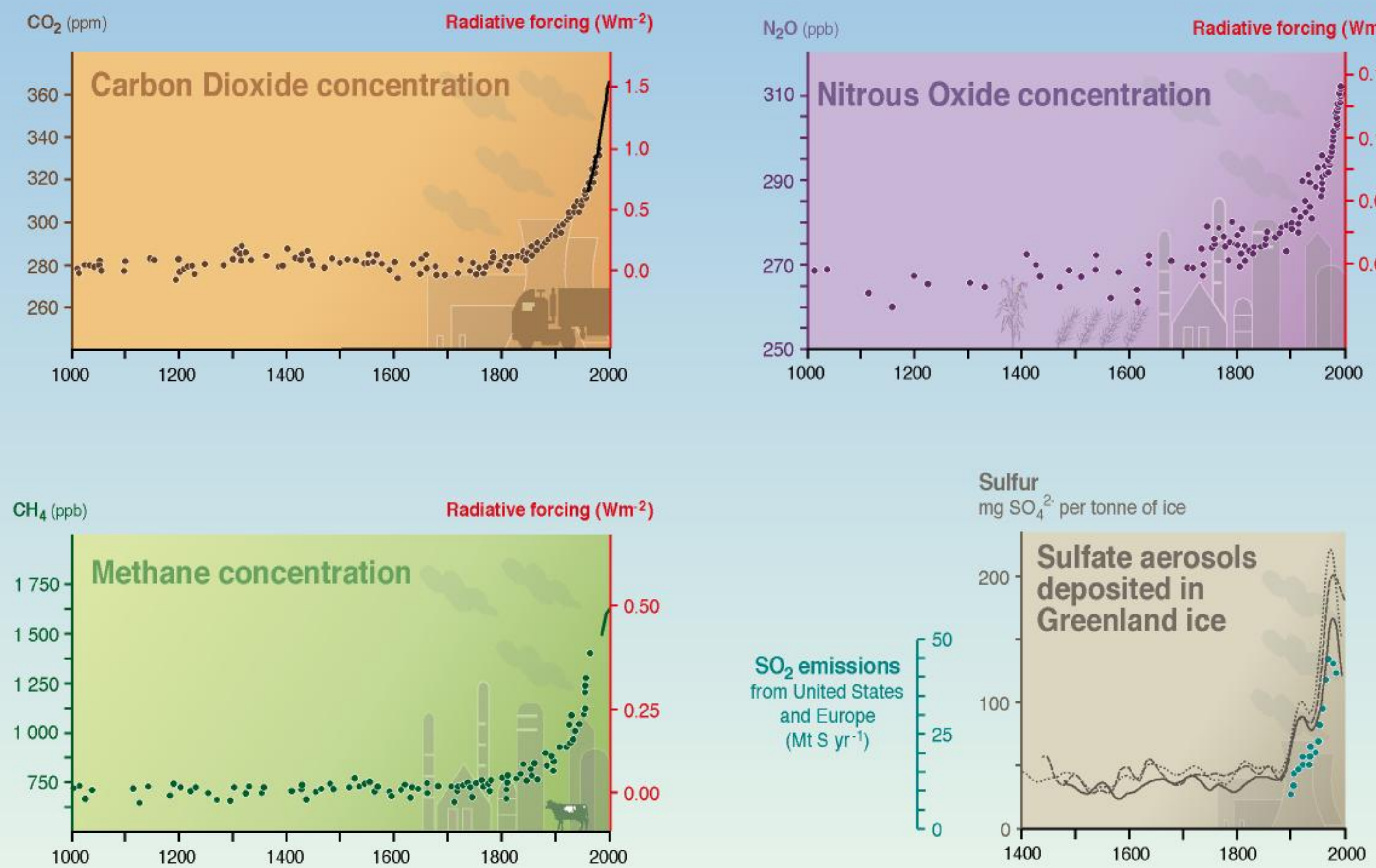
- Climate is a global public good
- Impacts (damages) are local
- Both emissions and impacts involve all agents and sectors
- Impacts will appear in the long term
- Abatement costs are borne in the short-medium term
- There is no supranational authority able to implement a global policy
- Climate agreements must be based on **self-enforcement**



SYR - FIGURE 2-3

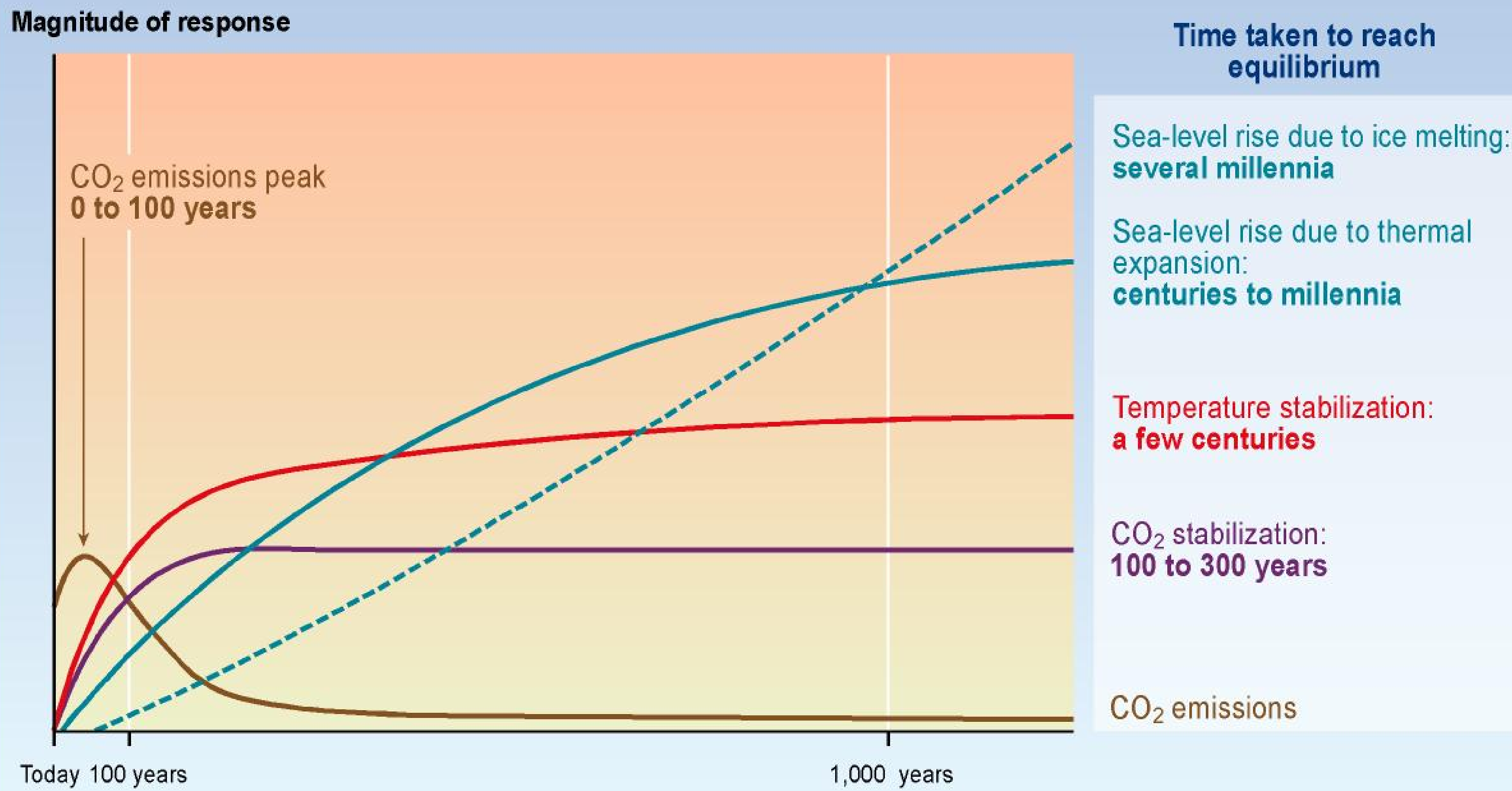
WMO UN

Indicators of the human influence on the atmosphere during the Industrial era



SYR - FIGU
WG1 FIGU

CO_2 concentration, temperature, and sea level continue to rise long after emissions are reduced



SYR - FIGURE 5-2

An effective climate policy thus requires…

١. To curb adequately worldwide GHG emissions, for a long time period:
BUT WHICH ABATEMENT ?

٢. For this to be effective, all countries should participate to the abatement effort:
BUT WHICH PARTICIPATION ?

The two questions are handled by using computational *integrated assessment models* (IAMs) and *game theory*.

2. The ClimNeg World Simulation model (CWS)

The CWS model is an Integrated Assessment Model (IAM).

An IAM is a combination of…

1. Damage functions
   monetarized environmental impacts
2. Abatement cost functions
   economic costs of pollution
3. Intertemporal optimization
   objective function

It thus interlinks…

1. the economy (Ramsey-type model of economic growth)
2. the climate (carbon cycle and temperature rise)
3. impacts of climate change and pollution abatement

Countries/regions in the CWS model

Country / region	CWS code
USA	USA
European Union (EU-15)	EU
Japan	JPN
China	CHN
Former Russian Union	FSU
Rest of the world	ROW

The economic model for country/region *i*

$$Y_{i,t} = Z_{i,t} + I_{i,t} + C_i\left(\mu_{i,t}\right) + D_i\left(\Delta T_t\right)$$

$$Y_{i,t} = A_{i,t} K_{i,t}^{\gamma} L_{i,t}^{١-\gamma}$$

$$K_{i,t+١} = \left[١ - \delta_K\right]^{١٠} K_{i,t} + ١٠ \, I_{i,t} \qquad \mathrm{K}_{\mathrm{i},٠} \text{ donné}$$

$$E_{i,t} = \sigma_{i,t}\left(1 - \mu_{i,t}\right) Y_{i,t}$$

$$C_i\left(\mu_{i,t}\right) = Y_{i,t} b_{i,1} \mu_{i,t}^{b_{i,2}}$$

$$D_i\left(\Delta T_t\right) = Y_{i,t} \theta_{i,1} \left(\frac{\Delta T}{2.5}\right)^{\theta_{i,2}}$$

Climate part

$$M_{t+1} = \overline{M} + \beta \sum_{i=1}^{n} E_{i,t} + \left(1 - \delta_M\right)\left(M_t - \overline{M}\right) \qquad M_0 \; donné$$

$$F_t = \frac{4.1 \, \ln\left(M_t / M_0\right)}{\ln\left(2\right)}$$

$$T_t^o = T_{t-1}^o + \tau_3 \left(T_{t-1} - T_{t-1}^o\right) \qquad T_0^o \, donné$$

$$\Delta T_t = \Delta T_{t-1} + \tau_1 \left[F_t - \lambda \Delta T_{t-1} \right] - \tau_2 \left(T_{t-1} - T_{t-1}^o\right) \quad \Delta T_0 \; donné$$

Calibration: some parameter values

δ_K	Taux de dépréciation du capital	0.10
γ	Elasticité de la production au capital	0.25
β	Part *aérienne* des émissions de CO_2	0.64
δ_M	Taux d'absorption naturel du carbone	0.08333
τ_1	Coefficient de transfert de l'équation de température	0.226
τ_2	Coefficient de transfert de l'équation de température	0.44
τ_3	Coefficient de transfert de l'équation de température	0.02
λ	Paramètre de *feedback*	1.41
$\overline{M}$	Concentration atmosphérique préindustrielle de CO_2	590
M_0	Concentration atmosphérique initiale de CO_2	783
ΔT_0	Variation initiale de la température à la surface du globe	0.622
T_0^o	Variation initiale de la température du fond des océans	0.108

Calibration *(con't)*

- Base year is 2000
- Assumptions, for each country/region, on the evolution of:
  - total factor productivity *(based on past evolutions)*
  - carbon intensity *(based on past evolutions)*
  - population level *(based on UN forecasts)*
- Simulation timespan: 2000 to 2250
- Step: 10 years

3. Three benchmark scenarios

- Laisser-faire (BAU, business-as-usual)
  no climate policies (non-rational, yet)
- Non cooperative (NASH equilibrium)
  no international agreement
  but each country implements its optimal domestic climate policy, while considering the strategy of the others as given
- Pareto-efficient (EFF solution)
  global policy that maximizes global welfare
  behind:
  optimal allocation of abatement efforts across countries

The objective functions

NASH scenario:

$$\underset{Z_{t,i},I_{t,i},\mu_{t,i}}{Max} \sum_{t=0} \frac{Z_{i,t}}{(1+\rho)^t}$$

BAU: same as NASH, but with $\mu = 0$

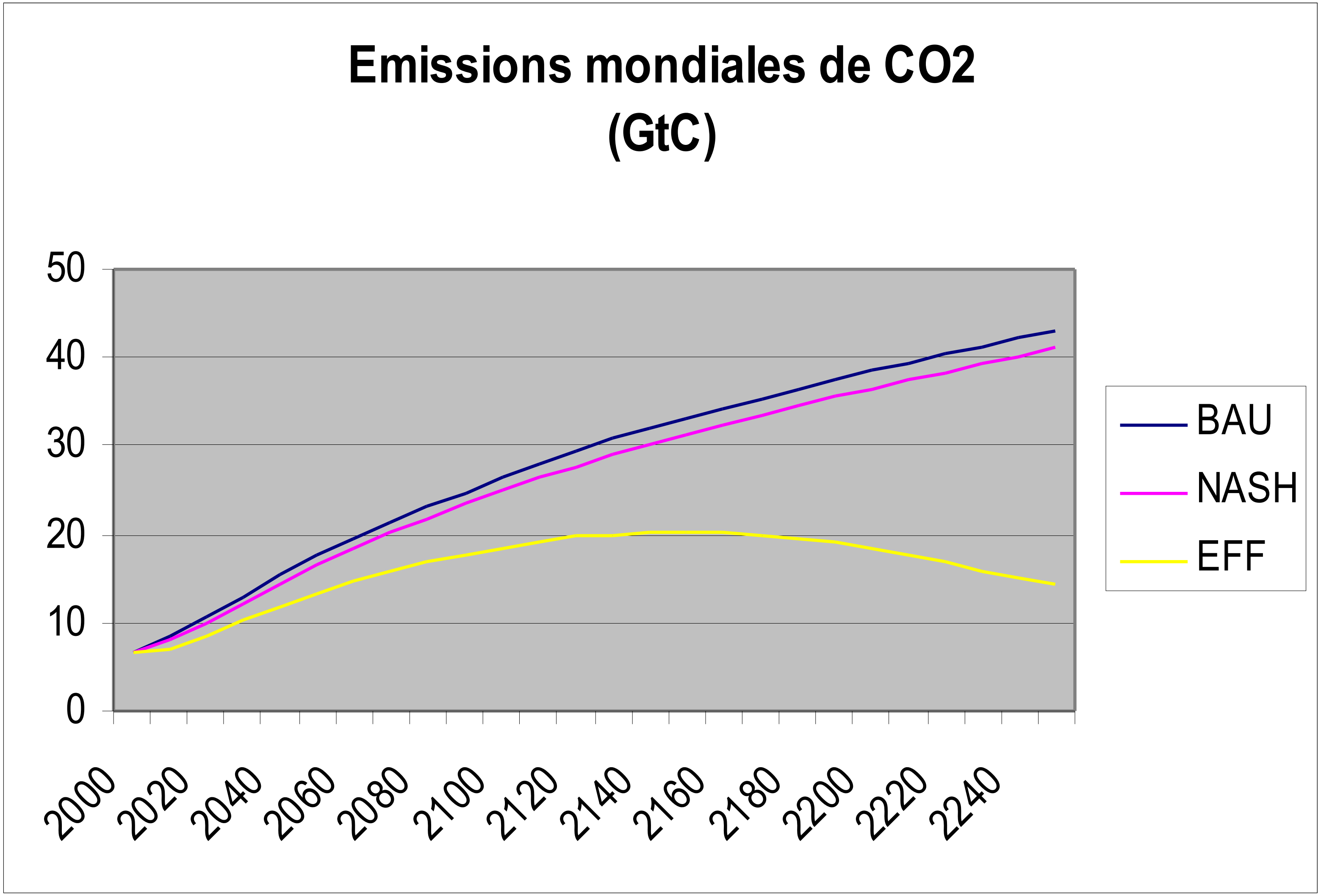
EFF scenario:

$$\underset{Z_{t,i},I_{t,i},\mu_{t,i}}{Max} \sum_{t=0} \sum_{i\in N} \frac{Z_{i,t}}{(1+\rho)^t}$$

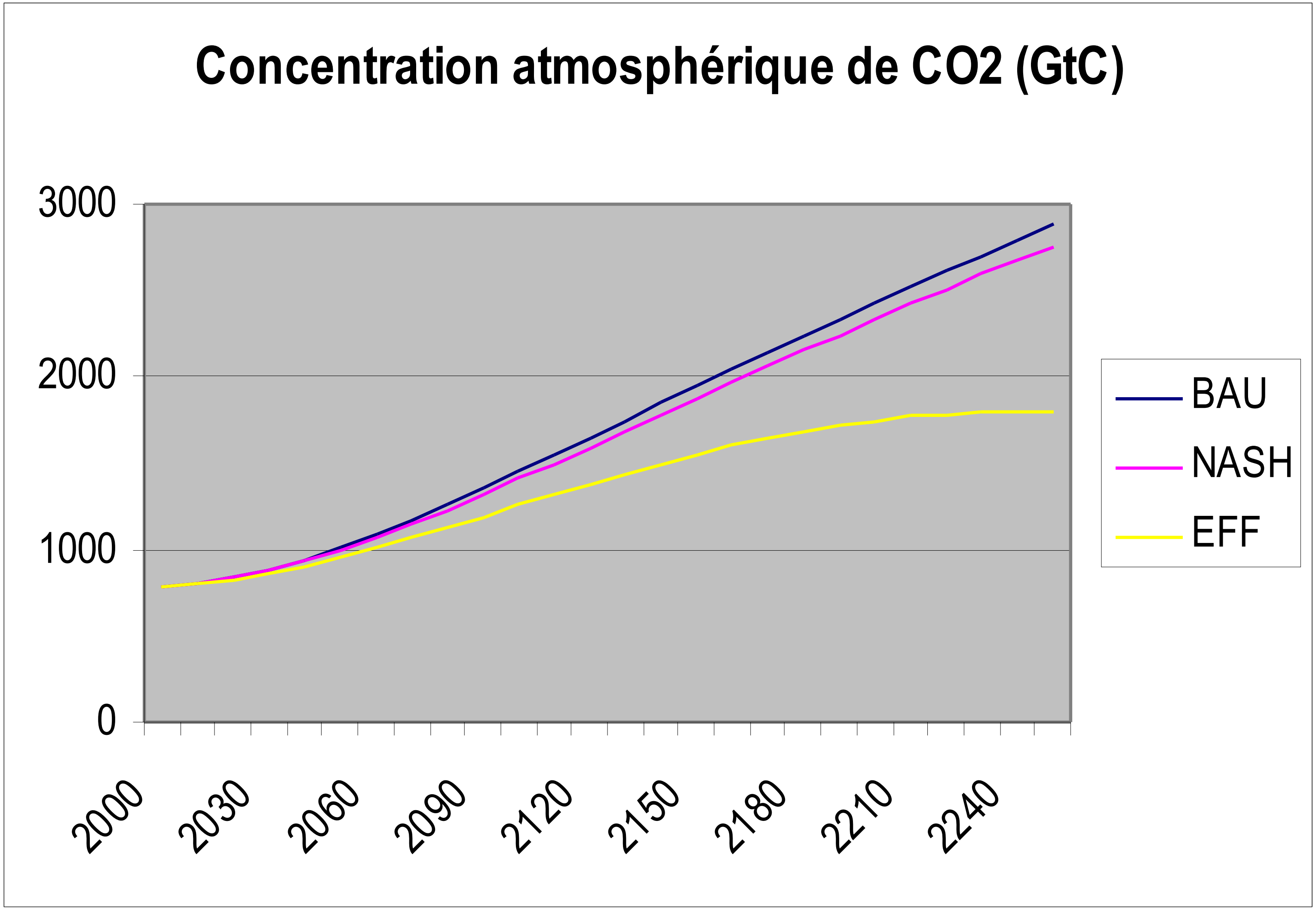
where *Z* is a ‘green’ consumption

Discount rates (per year):

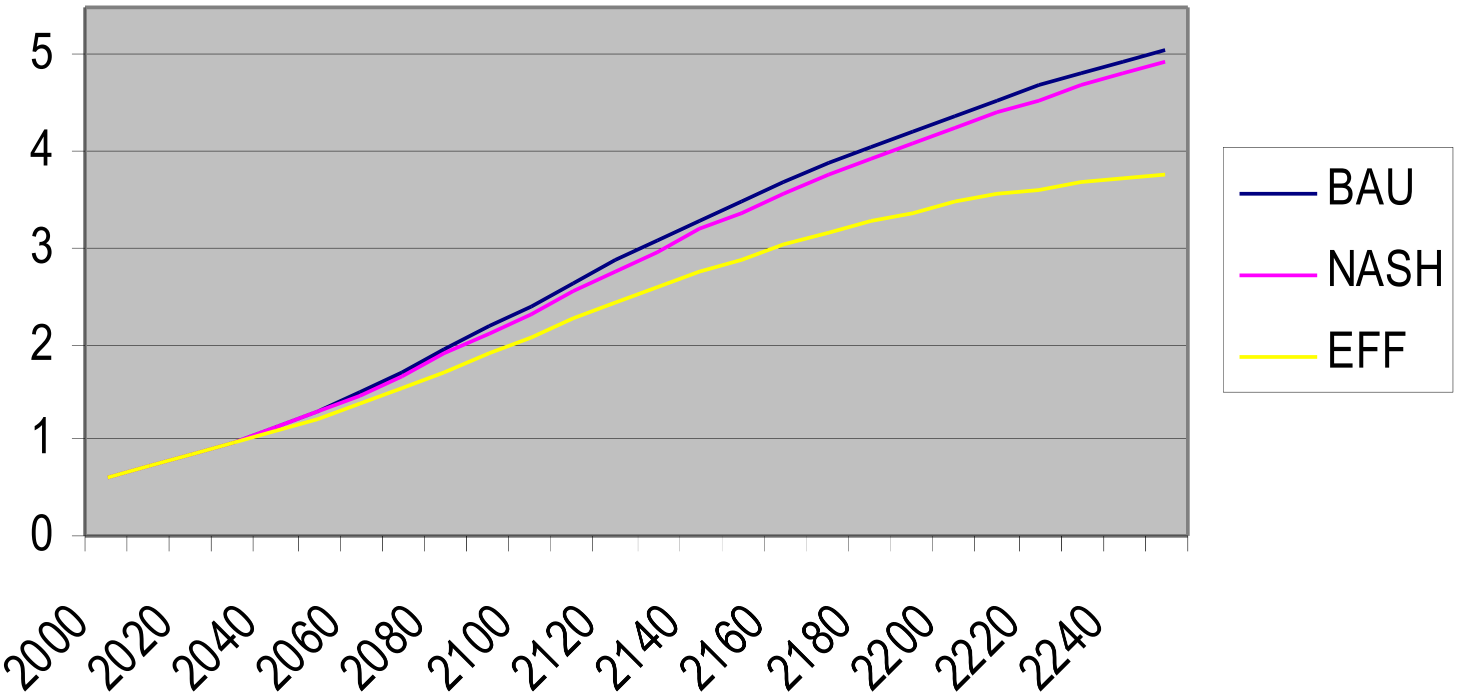
3.0% in CHN and ROW
1.5% in other (rich) countries

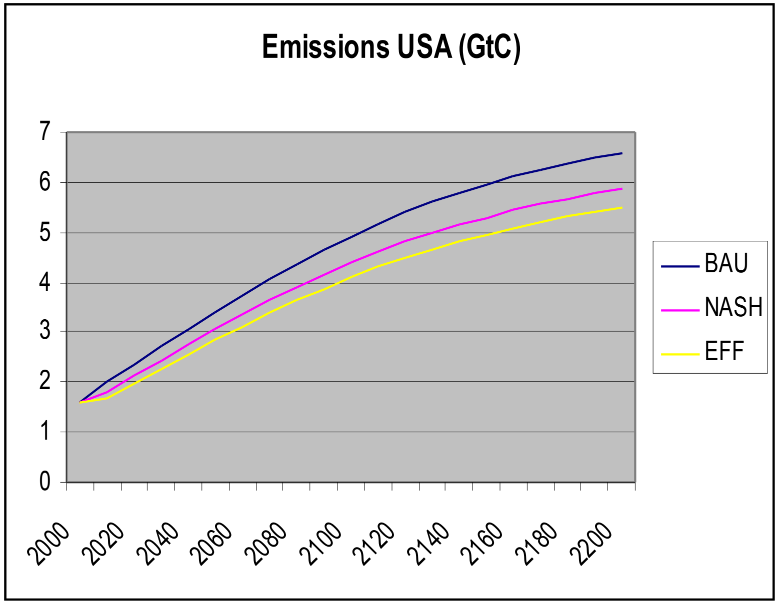


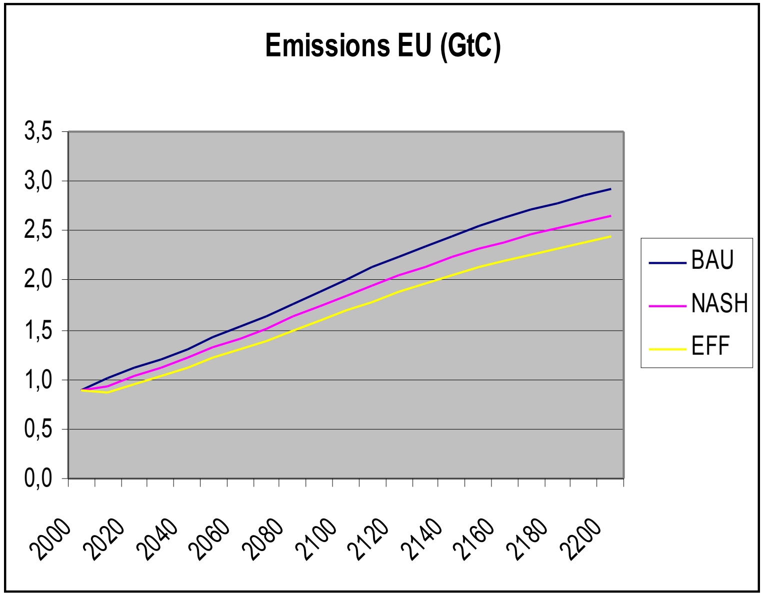
Emissions mondiales de CO2
(GtC)
50
40
30
20
10
0
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
2220
2240
BAU
NASH
EFF

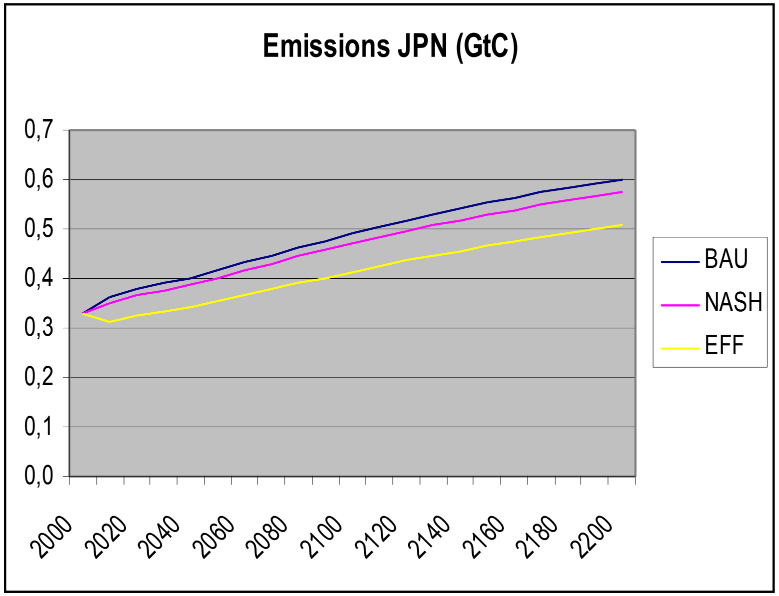

Concentration atmosphérique de CO2 (GtC)
3000
2000
1000
0
2000
2030
2060
2090
2120
2150
2180
2210
2240
BAU
NASH
EFF

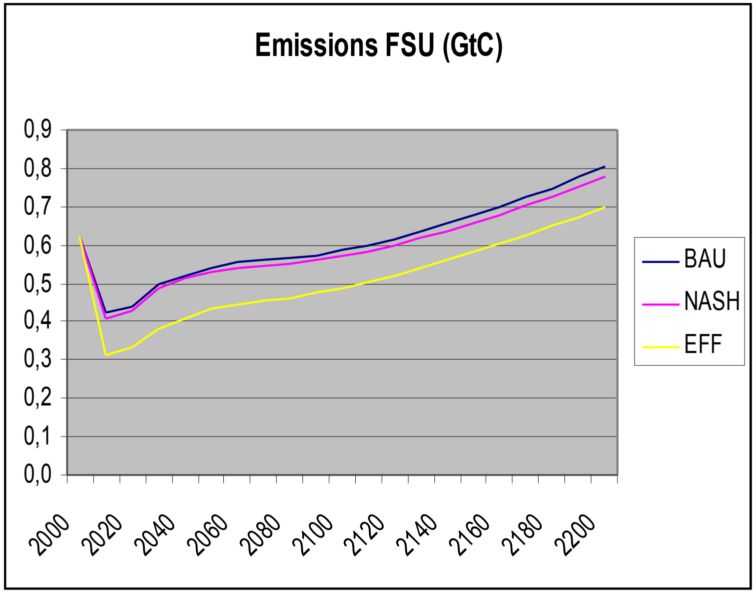
Augmentation de la température moyenne à la surface du globe (°C)

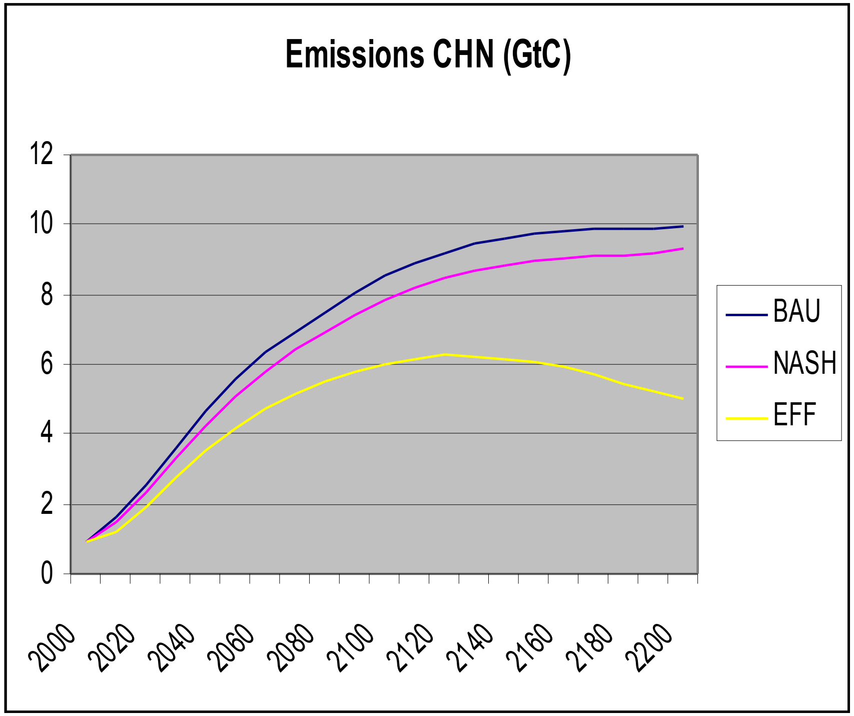


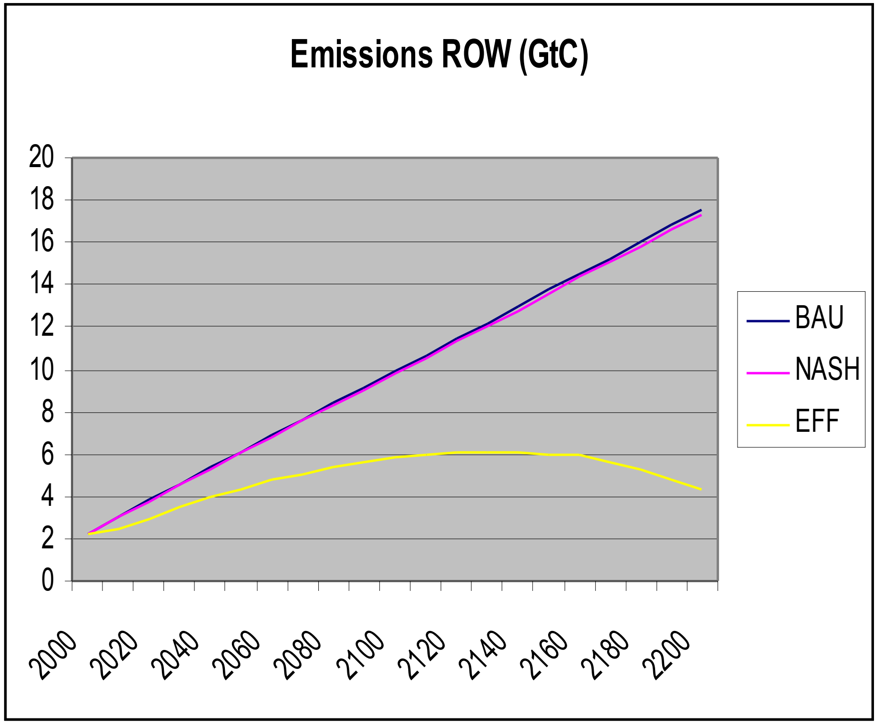

Emissions USA (GtC)
0
1
2
3
4
5
6
7
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF


Emissions EU (GtC)
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF


Emissions JPN (GtC)
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF


Emissions FSU (GtC)
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF


Emissions CHN (GtC)
12
10
8
6
4
2
0
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF


Emissions ROW (GtC)
20
18
16
14
12
10
8
6
4
2
0
2000
2020
2040
2060
2080
2100
2120
2140
2160
2180
2200
BAU
NASH
EFF

Comparison of welfare
(*i.e.* discounted green consumption)

	BAU	NASH	NASH/BAU	EFF	EFF/BAU	EFF/NASH
USA	148099,9	148240,9	**0,10%**	148924,5	**0,56%**	**0,46%**
JPN	30615,57	30641,26	**0,08%**	30751,82	**0,45%**	**0,36%**
EU	108290,9	108395,6	**0,10%**	108871,5	**0,54%**	**0,44%**
CHN	36121,31	36148,81	**0,08%**	36060,34	**-0,17%**	**-0,24%**
FSU	9733,248	9743,806	**0,11%**	9788,157	**0,56%**	**0,46%**
ROW	54053,59	54096,63	**0,08%**	53875,59	**-0,33%**	**-0,41%**
WORLD	386914,6	387267	**0,09%**	388271,9	**0,35%**	**0,26%**

4. Some cooperative and non cooperative game theory concepts

CWS has been used to study coalition formation in two ways:

1. cooperative approach
   (Eyckmans and Tulkens, 2003)
2. non-cooperative approach
   (Carraro, Eyckmans and Finus, 2006)

When a coalition is not **stable**, both approaches suggest **transfers schemes** to make it stable.

A few notations

N is the set of players (countries or regions)

i refers to players ($i = 1, \ldots n$)

S is a coalition

v(.) is the worth of a coalition

y is an imputation for the grand coalition $y = (y_1, \ldots, y_i, \ldots y_n)$

Stability concepts under the cooperative approach

The cooperative approach focuses on strategies chosen by the 'grand coalition'. Such strategies are stable if:

- no player is better-off in the absence of cooperation
- no group of players can do better in smaller coalitions

i.e., the following two properties are satisfied:

Individual rationality: $\forall i \in N, \quad y_i \geq v(\{i\})$

Coalitional rationality: $\forall S \subset N, \quad \sum_{i \in S} y_i \geq v(S)$

Stability concepts under the non-cooperative approach

The non-cooperative approach considers the individual payoffs assigned to every player, being inside or outside a coalition.

A coalition is stable if:
- no insider prefers to leave unilaterally, and
- no outsider prefers to join, rather than to stay aside

Let $v_i(S)$ be the individual payoff of player *i* when coalition *S* is formed.

Internal stability: $\forall i \in S, \quad v_i(S) \geq v_i(S \setminus \{i\})$

External stability: $\forall i \notin S, \quad v_i(S) \geq v_i(S \cup \{i\})$

Transfers schemes

If a coalition is not stable, some transfers schemes may induce stability.

Cooperative approach

the grand coalition can be stabilized by 'GTT transfers': the **surplus** of cooperation is divided among countries, and each region receives at least its consumption level when no cooperation.

Transfers are given by

$$\Psi_i = -\left(W_i^{eff} - W_i^{nash}\right) + \pi_i \left(\sum_{j \in N} W_j^{eff} - \sum_{j \in N} W_j^{nash}\right)$$

$$with \quad \pi_i \geq 0, \forall i, \quad and \quad \sum_i \pi_i = 1$$

Transfers schemes (con't)

Non-cooperative approach

No explicit rule, but uses the notion of *potential internal stability* (PIS):

A coalition is PIS if it guarantees to its members at least their free-rider payoff, that is,

$$v(S) \geq \sum_{i \in S} v_i\left(S \setminus \{i\}\right)$$

Transfers schemes (end)

Difference between the two approaches

- The cooperative approach assumes that, if a country free-rides on the agreement, the whole coalition collapses.
- The non-cooperative approach assumes that, if a country free-rides, the other countries in the coalition stick together.

5. Analysis of climate coalitions

How do we proceed?

١. We run the model under the NASH and EFF scenarios up to 2250

٢. We run the model for all the 63 possible coalitions (the 64th being ‘all singletons’)

٣. For each of these coalitions,
- we compute its worth (sum of discounted consumption),
- we check whether it is IS, ES, PIS,
- we calculate the GTT transfers

Some results : stability (1/3)

Cooperative approach

1. The grand coalition (EFF) is not stable: 18 smaller coalitions can do better (and thus will block the grand coalition)
2. GTT transfers can make the grand coalition stable

Non-cooperative approach

1. Only 7 coalitions are IS, all being small (2 or 3 countries); the grand coalition is not IS
2. Only one coalition is both IS and ES: {USA, EU}
3. With transfers, all 2- and 3-country coalitions are PIS, while only one 5-country is : {USA, JPN, CHN, FSU, ROW}

Some results : ‘homogeneity’ (2/3)

Countries can be split into two categories:

- developped countries: USA, JPN, EU
- developping ones: CHN, ROW
- … and a ‘free electron’, FSU

An **homogeneous coalition** is a coalition formed by countries from a single categorie (+/- FSU)

1. Out of the 7 IS coalitions, 5 are homogeneous ones
2. All these 5 IS-homogeneous involve FSU
3. Only 11 heterogeneous coalitions (out of 42) are PIS
4. Kyoto is ES and PIS, while Kyoto\{USA} is not ES: the USA would be better-off by joining back Annex B !

So: **homogeneity seems to foster stability**

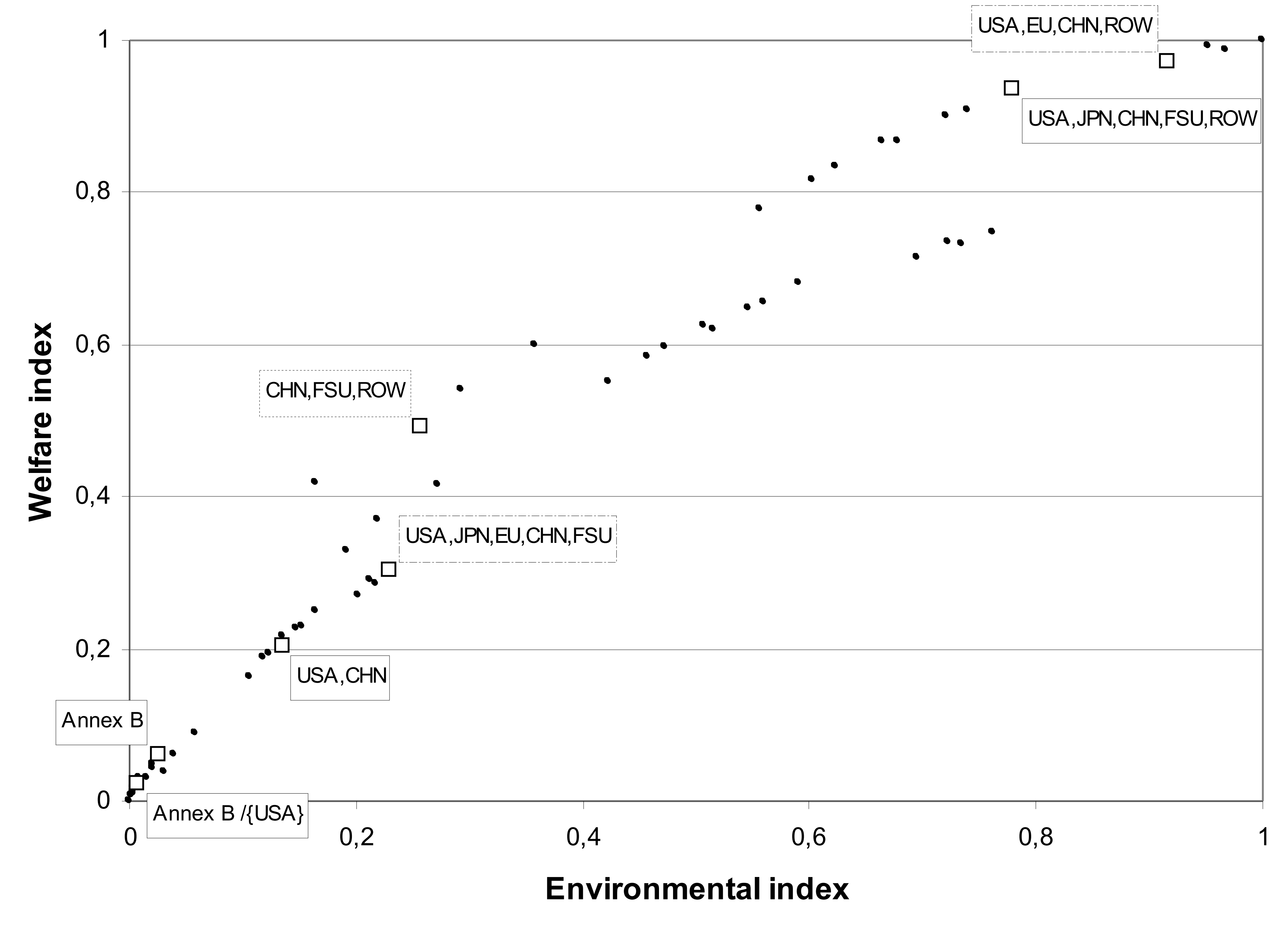
Some results : global outcome (3/3)

What is an ‘efficient’ climate agreement?
- a large number of countries?
- a small number of countries?
- a split between rich and poor countries?

To assess the **efficiency** of coalitions we built up two indexes:

1. the aggregate welfare level reached at the world level
2. the environmental performance, expressed as carbon concentration in 2250.

These indexes are normalized so that 1 corresponds to the EFF solution and 0 corresponds to the NASH solution.


USA,EU,CHN,ROW
USA,JPN,CHN,FSU,ROW
CHN,FSU,ROW
USA,JPN,EU,CHN,FSU
USA,CHN
Annex B
Annex B /{USA}
Welfare index
Environmental index
1
0,8
0,6
0,4
0,2
0
0
0,2
0,4
0,6
0,8
1

Conclusion (1/2)

- The computational CWS model allows to *illustrate* theoretical insights in terms of coalition formation
- Importance of sensitivity analyses to check the robustness of the results
- Normative exercise:
  - says **what** each country **should** do to maximise its own welfare
  - but: nothing on **how** such agreements could be reached
- Descriptive exercise:
  - exhibits the rational behind countries' strategies (cost-benefit analysis)

Conclusion (2/2)

- Is it a problem to assume that countries’ strategy lies on cost-benefit analysis?
- Is it selfishness?
- What about national policies?
- What are these ‘transfers’ among countries?
- Main shortcomings of the methodology?

References

- Carraro, C., Eyckmans, J. and Finus, M. (2006). `Optimal transfers and participation decisions in international environmental agreements', Review of International Organisations, 1(4), 379-396.
- Eyckmans, J. and Tulkens, H. (2003). `Simulating coalitionally stable burden sharing agreements for the climate change problem', Resource and Energy Economics, 25, 299-327.
- Chander, P. and Tulkens, H. (1997). `The core of an economy with multilateral environmental externalities', International Journal of Game Theory, 26, 379-401.
- Bréchet, Th., Gerard, F. and Tulkens, H. (2007). 'Efficiency *vs* stability of climate coalitions: a conceptual and computational appraisal', CORE discussion paper 2007/3.