Adaptive Decisionmaking and Cooperative Management of Uncertain Climate Change

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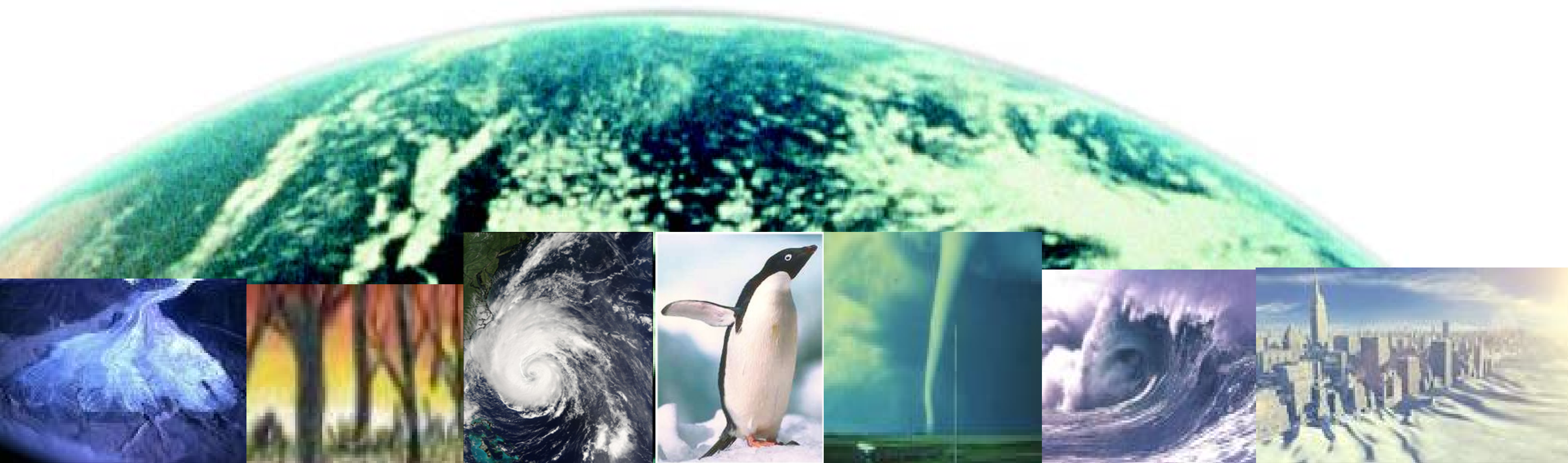
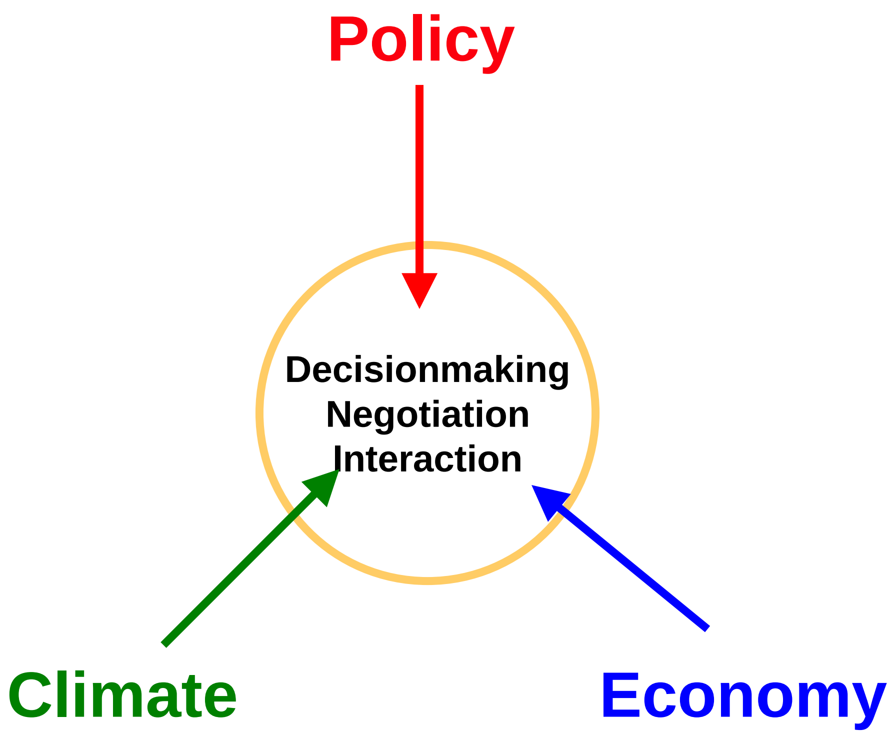
November 8, 2006



Outline

1. Integrated assessment and adaptive decision-making on energy and climate change
2. Data, uncertainty and risk
3. Adaptive strategies vs. optimal control
4. Interactive decision-making, cooperation and coalition formation among multiple actors
5. Summary and outlook

Integrated Approach



UN Framework Convention on Climate Change

UNFCCC Article 2 ultimate objective (Rio 1992):

"stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

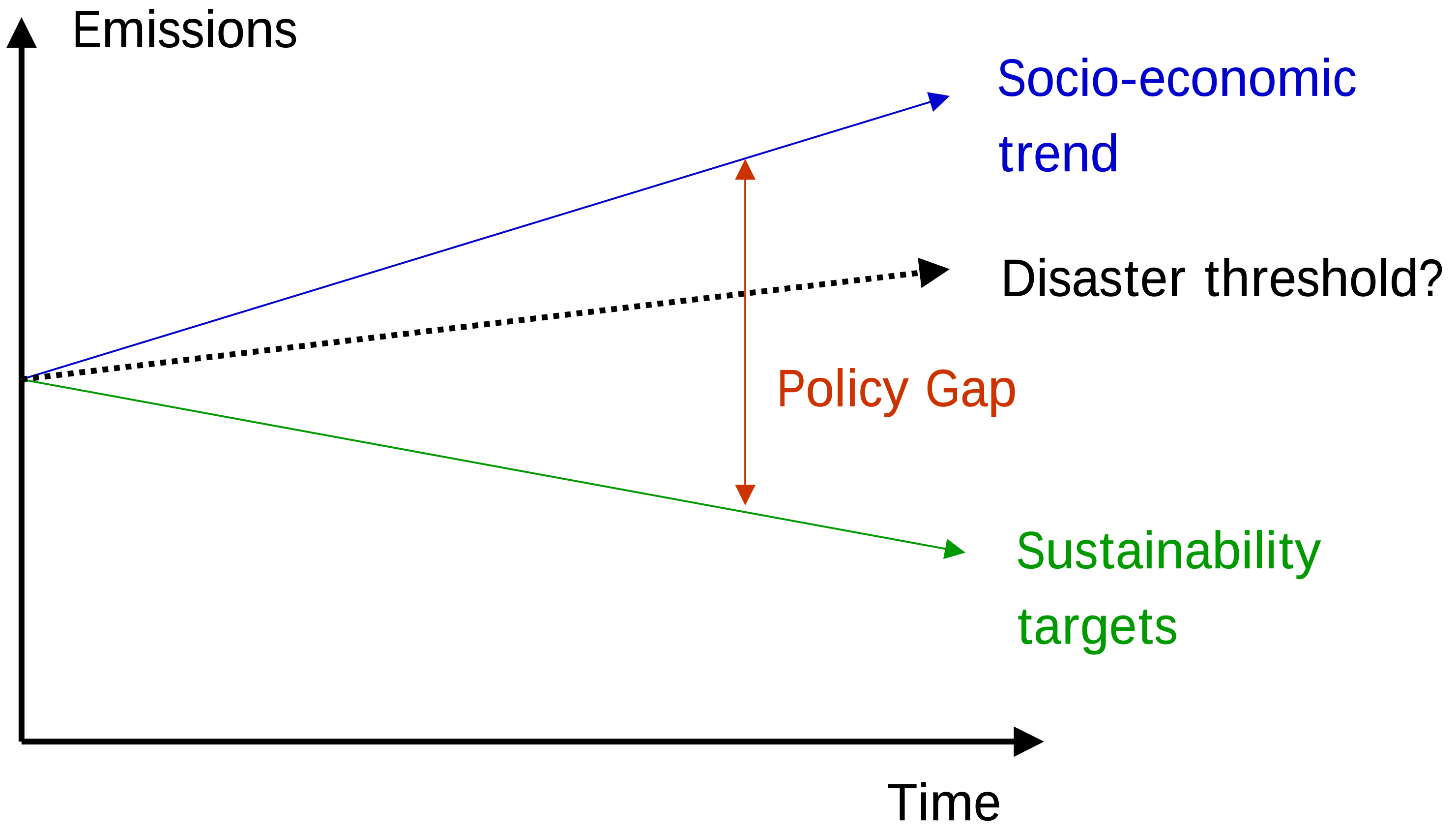
Such a level should be achieved within a time-frame sufficient

- to allow ecosystems to adapt naturally to climate change,
- to ensure that food production is not threatened and
- to enable economic development to proceed in a sustainable manner."

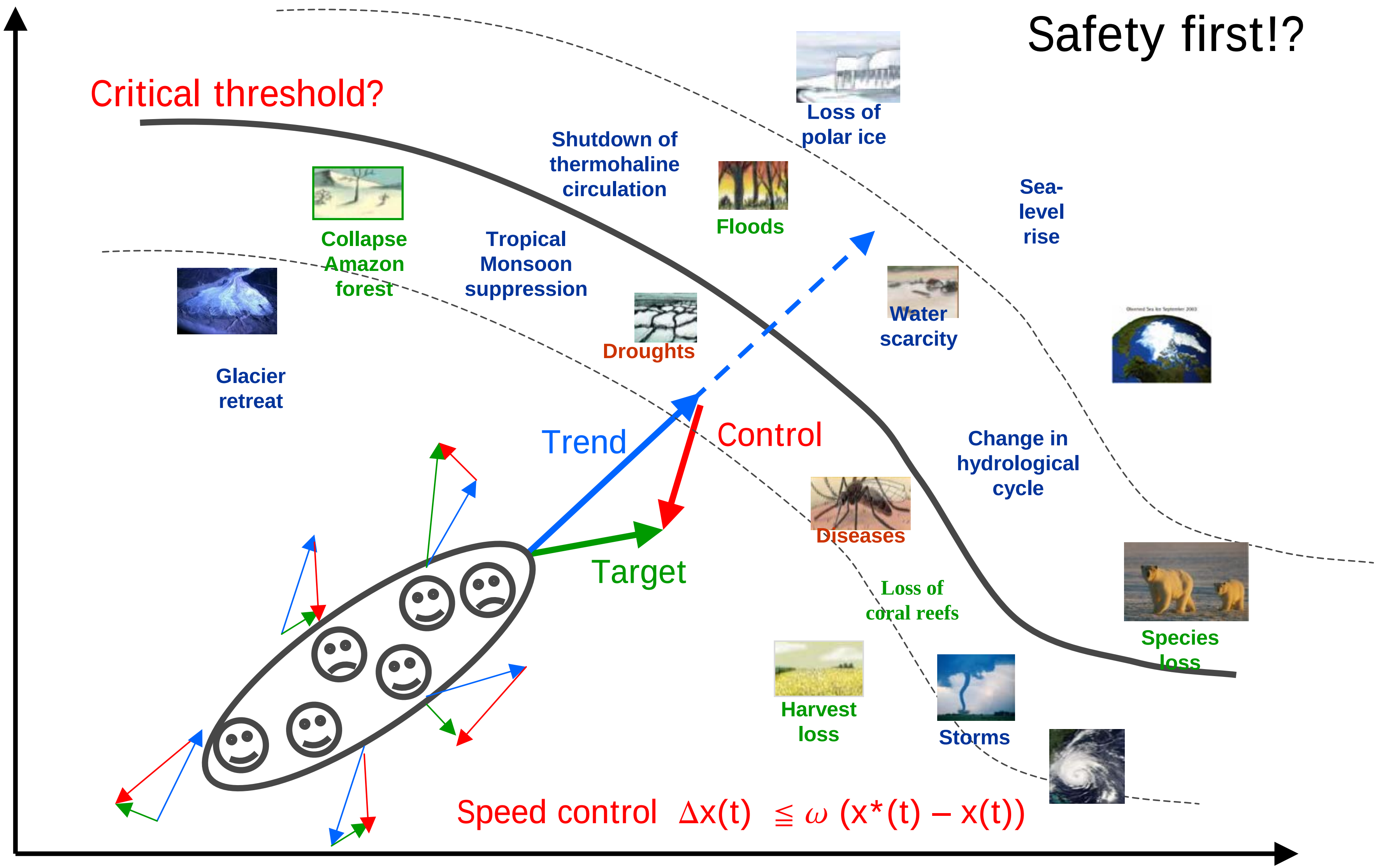
1997 Kyoto Protocol to the UNFCCC:

- Greenhouse gas (GHG) emission reductions for industrialised countries: average -5.2% of 1990 level until 2008-2012
- In force since February 16, 2005

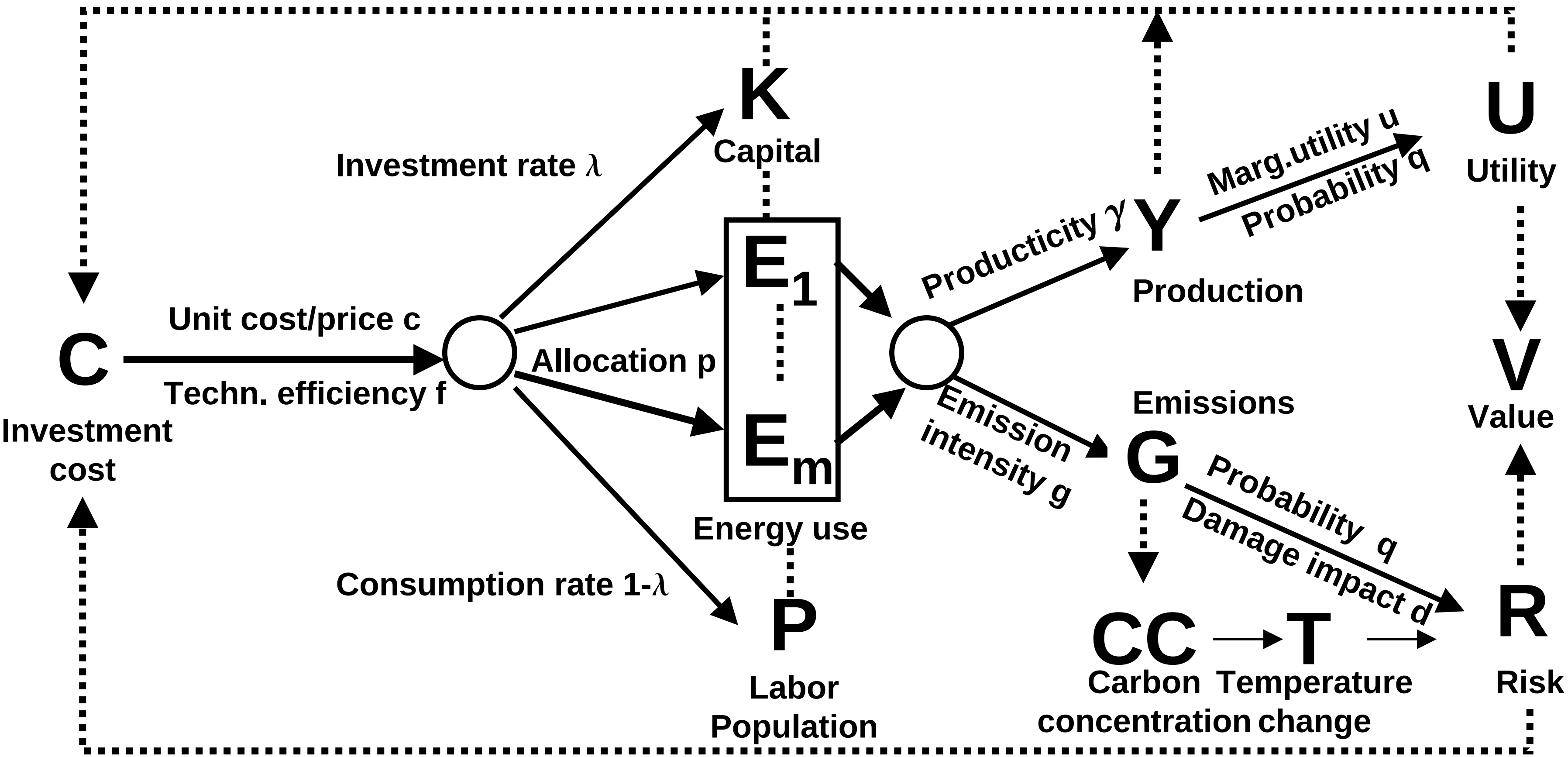
The Gap between Trends and Targets



Adaptive Control: Where to Go and How Fast?



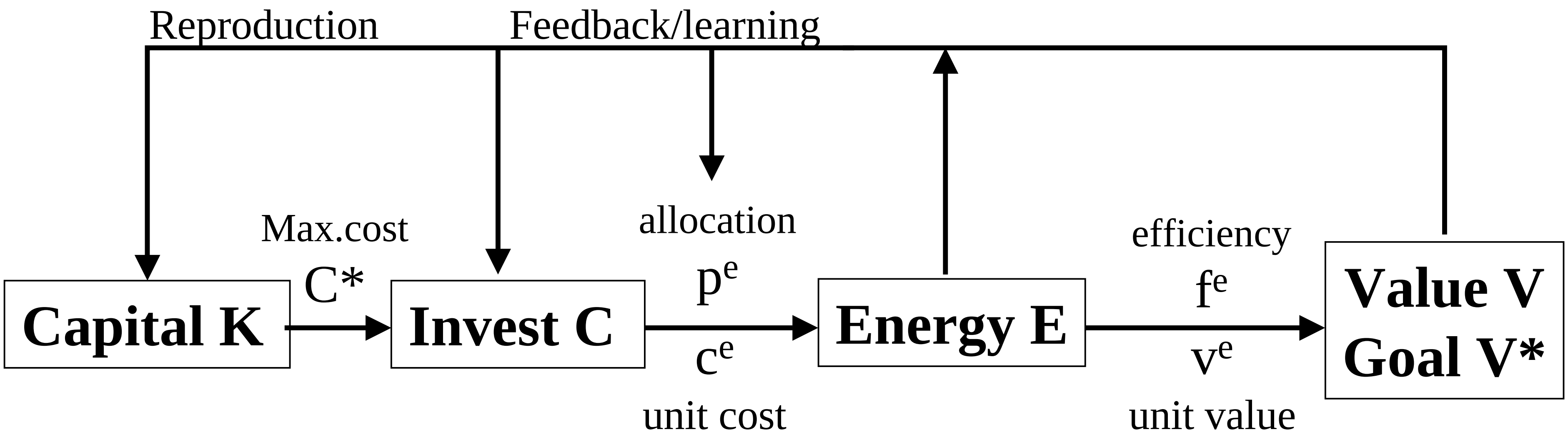
Integrated Decision-making on Energy Options



$$U(E) = q\, f\, \gamma\, p\, C(E) / c$$

$$R(E) = q\, (D/G)\, (G/E)\, (E/Y)\, (Y/P)\, P = q\, d\, g\, e\, y\, P$$

The Single Actor Feedback Loop



$$\Delta V = v^e \, \Delta E = f^e \, C$$

$$\Delta C = - k \, C \, (C^* - C) \, (V - V^* + \tau \, \Delta V)$$

Logistic budget restraint — Value driver

C : Cost invested in a given period (flow variable) for changing system state x with $0 \leq C \leq C^*$

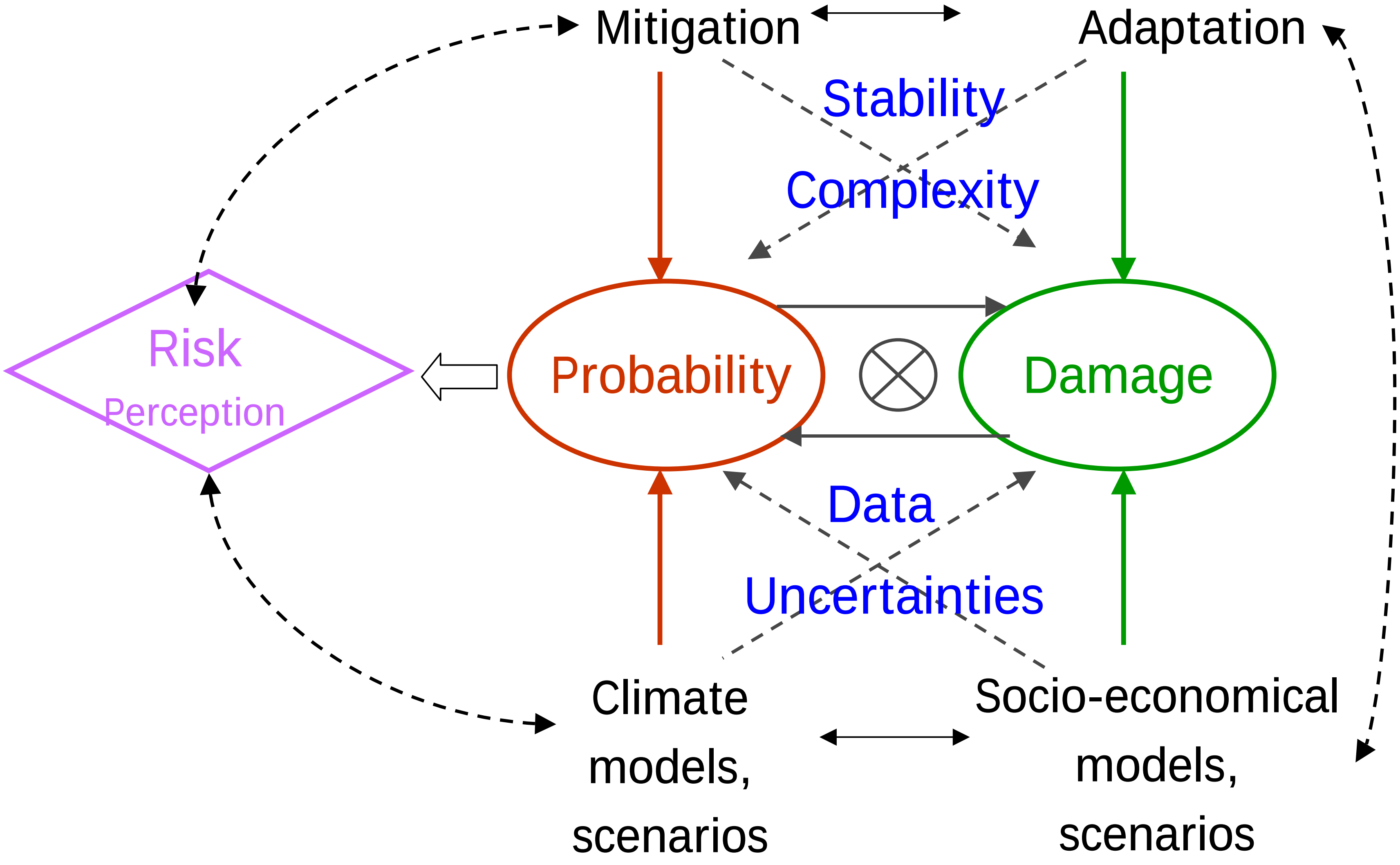
$f^x = p^x v^x / c^x$ action efficiency, depending on unit cost c^x, unit value v^x and

p^x : percentage of cost allocated to action path x.

k cost reactivity in logistic reaction function

τ desired decay time of value gap

Factors of Climate Risk Assessment



Data-calibrated Econometric Model with Basic Climate Model

- Optimization of time-integrated discounted utility of per capita consumption using log-linear production functions in capital, labor, energy, and development with constant returns to scale.

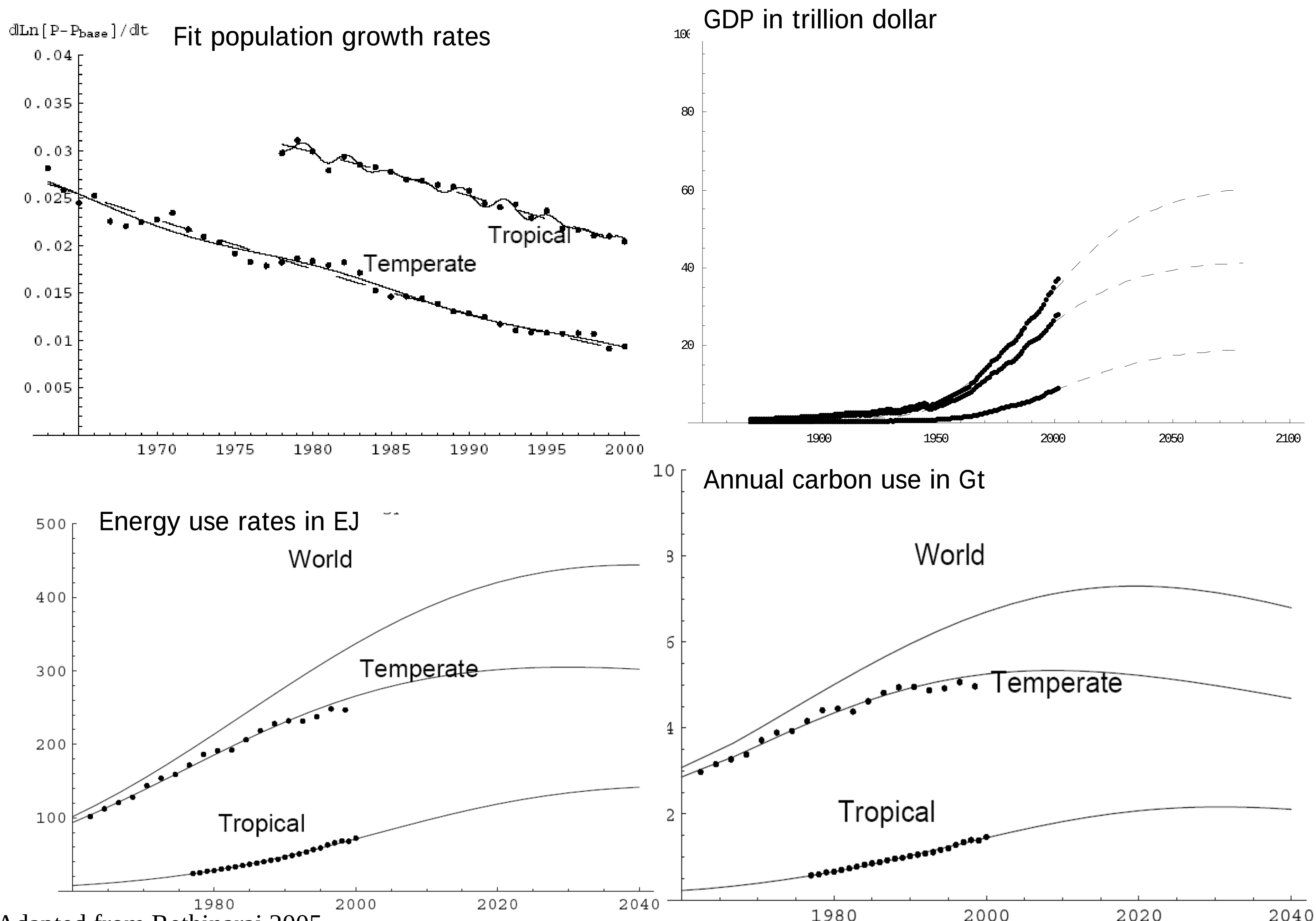
- Energy production is log-linear in labor, capital, and development. Energy production, total capital and population are measured in units of their steady-state limits.

- Development index grows logistically with time in proportion to population and is the ratio of total labor to its steady-state limit. Population growth rates are used to calibrate the development index.

- Production efficiency decreases linearly with decreasing carbon intensity of energy production, which is data calibrated for the past and determined by theories of fuel source substitution and international cooperation on emissions limitations for more distant future.

- Country data and simulation results are clustered into different regional aggregations (tropical region within forty degrees north and south and temperate region).

Data and Projections for Population, GDP, Energy, Carbon

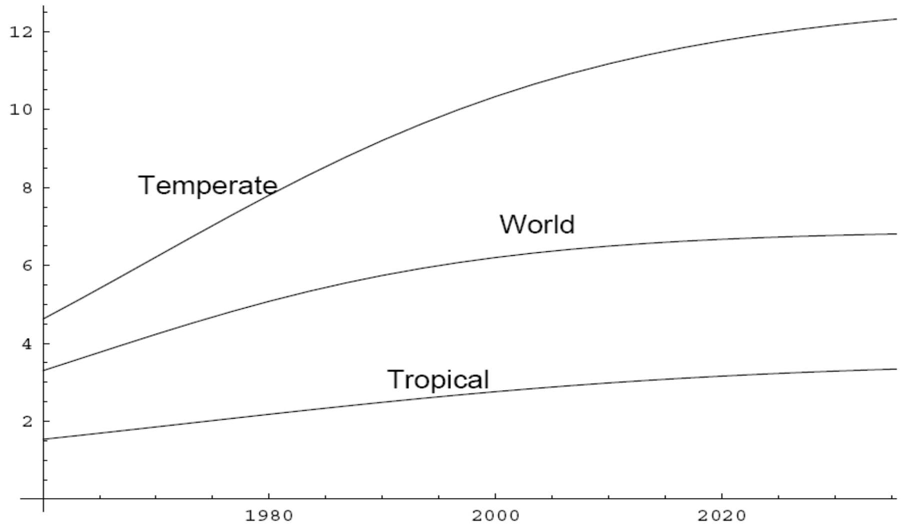


Adapted from Rethinaraj 2005

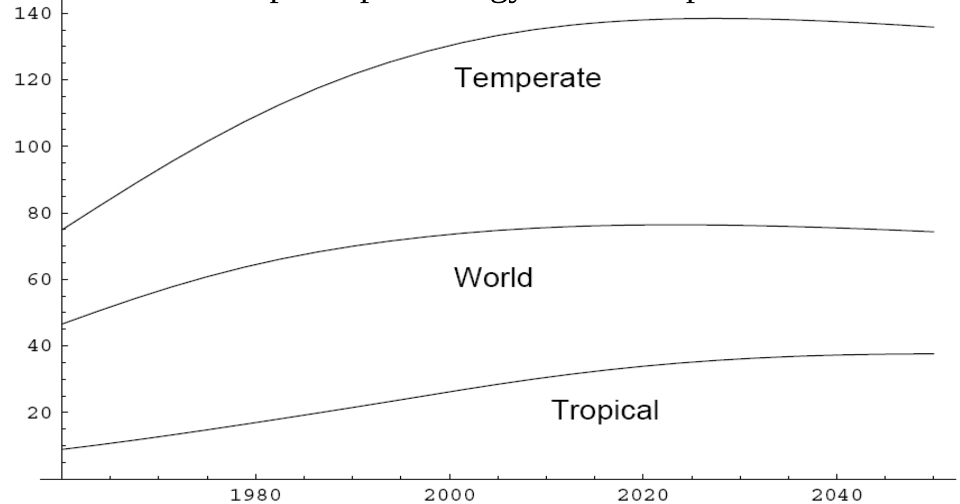
Relevant Factors

Rethinaraj 2005

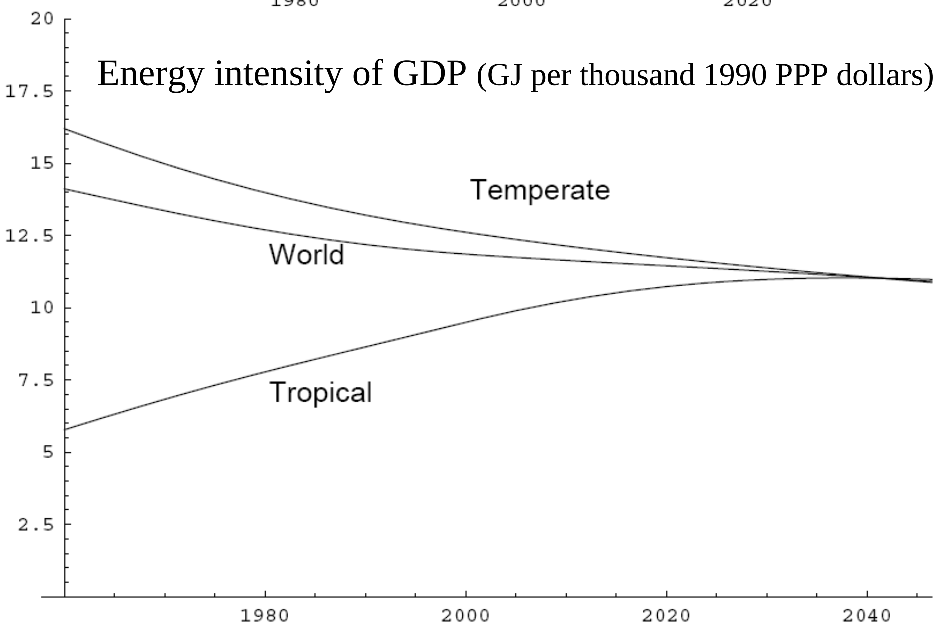
Annual GDP per capita´in thousand 1990 dollars/person



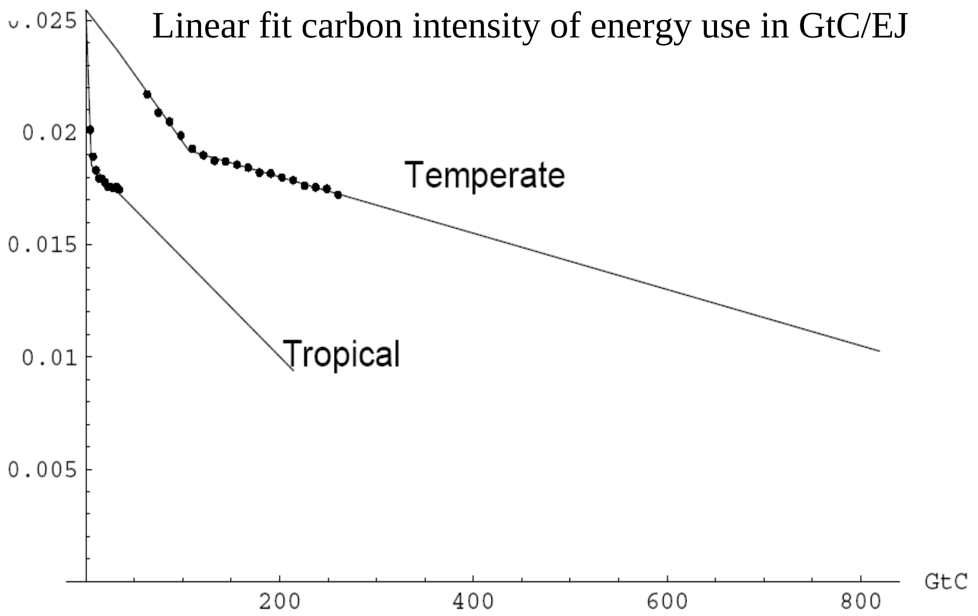
Annual per capita energy use in GJ/person



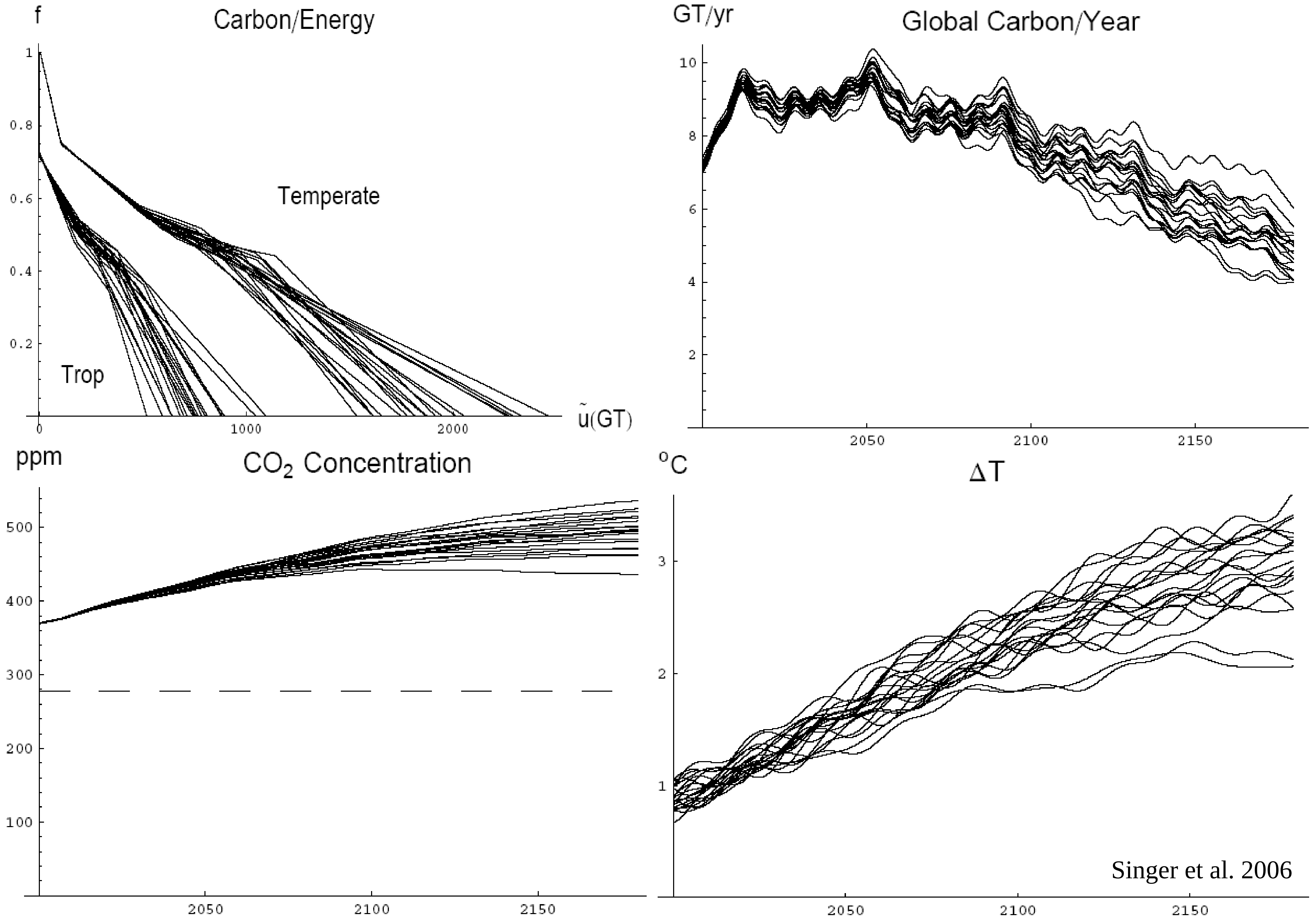
Energy intensity of GDP (GJ per thousand 1990 PPP dollars)



Linear fit carbon intensity of energy use in GtC/EJ

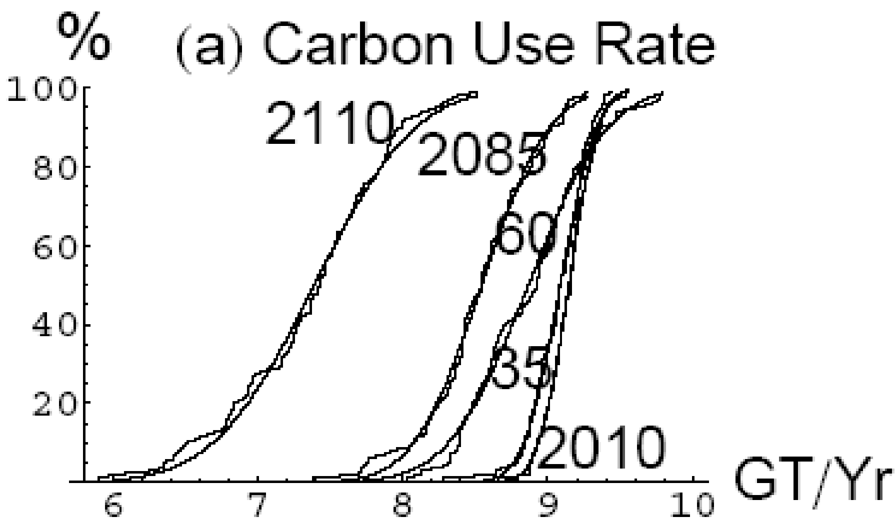


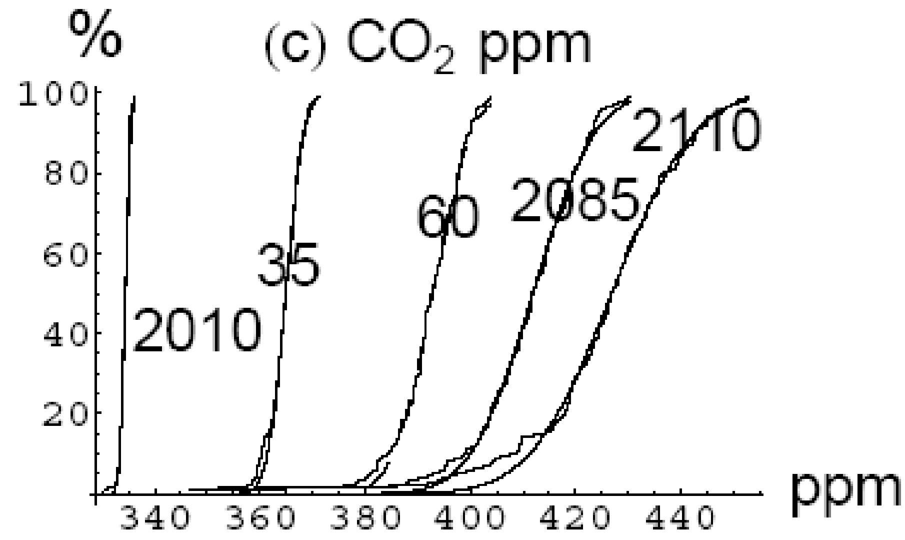
Randomly Sampled Climate Variables

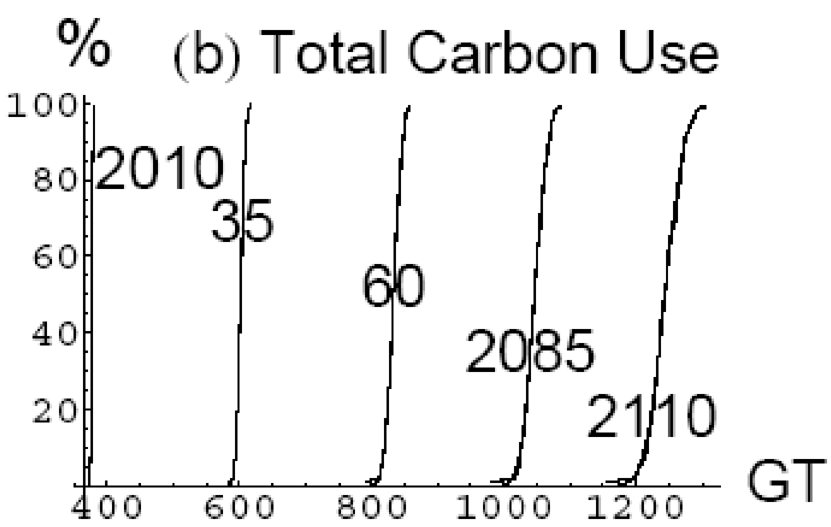


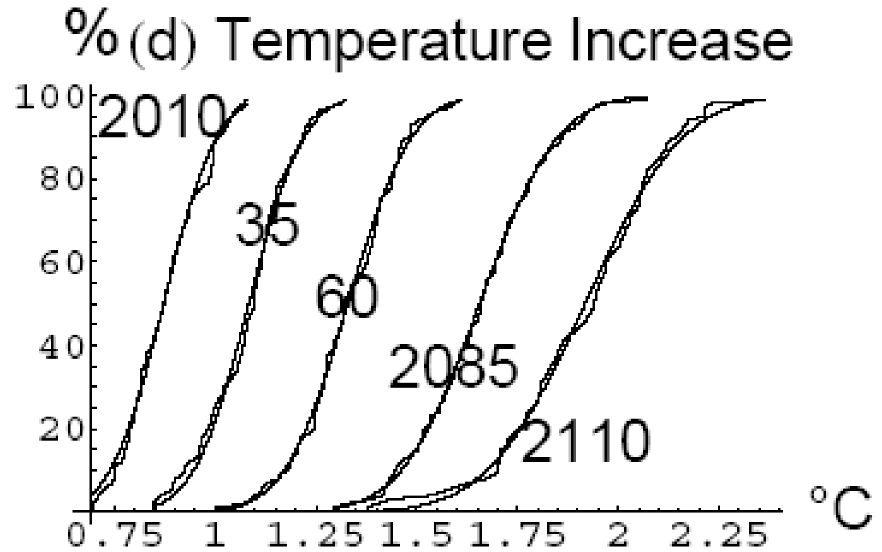
Cumulative Probability Distributions

Cumultative probability distribution centiles (jagged plots), and cumulative normal distributions fit to central 95 centiles (smooth curves) for indicated years (Singer et al. 2006)

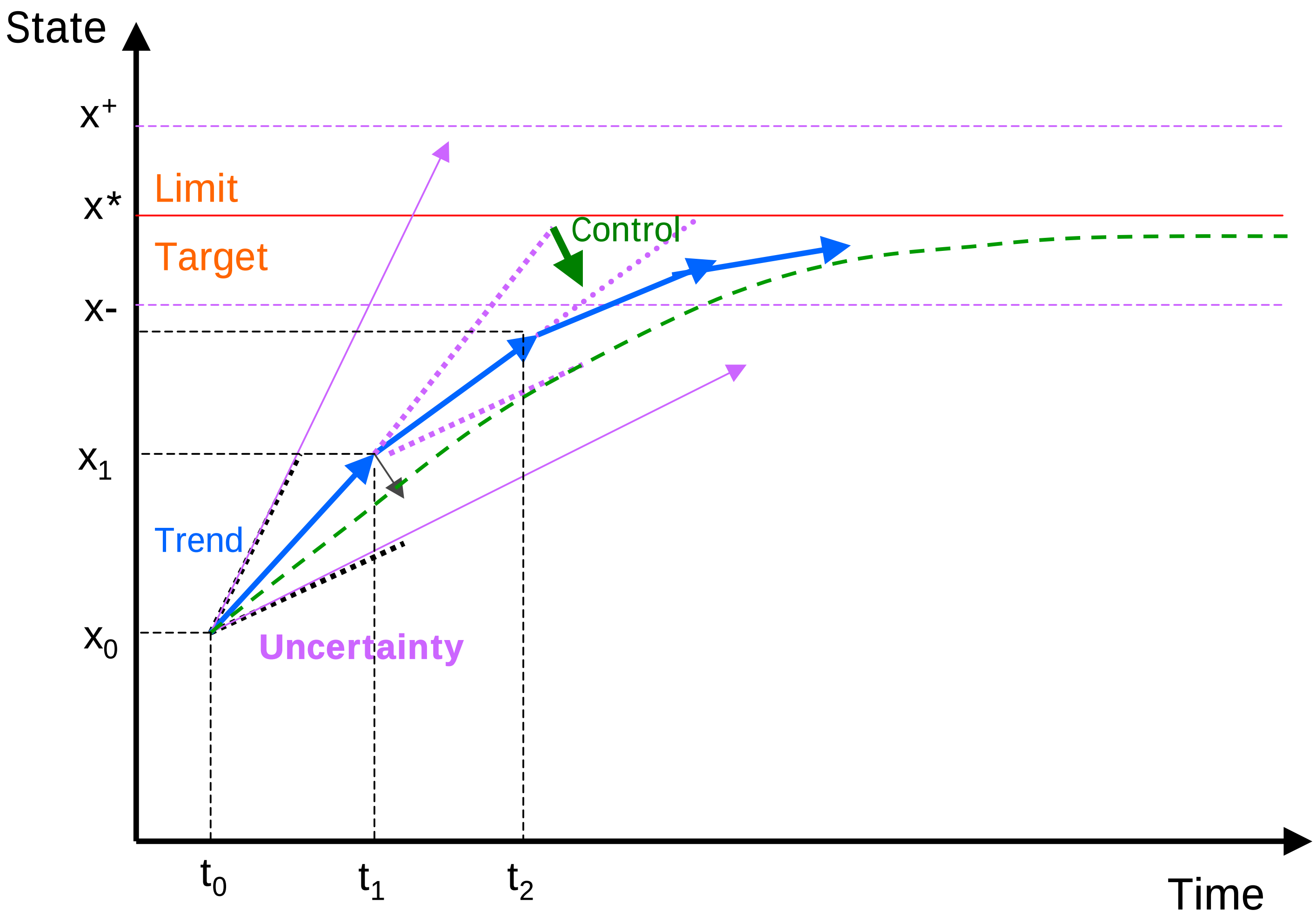








Adaptive Control Under Uncertainty



Adaptive decision rules: $\Delta x(t) = w(x,t)\ D(x,t)$

Speed control $\Delta x(t) \leqq w\ (x^*(t) - x(t))$

Optimal and adaptive control

Optimal control approach: Control dynamic system (for some initial and terminal conditions)

$$\dot{x} = f(x, u)$$

with state variables $x(t) \in X(t)$ and control variables $u(t) \in U(t)$ to maximize time discounted value:

$$Max_{u \in U} \int_0^T V(x(t), u(t)) e^{-\rho t} dt$$

Viable control approach (target setting): Control dynamic system

$$\dot{x} = f(x, u)$$

to realize given target path $x^*(t)$ or dynamic system $\dot{x} = g(x, t)$ by choice of $u(t) \in U$. Then

$$\ddot{x} = \frac{\partial f}{\partial x}\dot{x} + \frac{\partial f}{\partial u}\dot{u} = \frac{\partial g}{\partial x}\dot{x}$$

With $\dot{x} = g(x)$ and f_x, f_u, g_u for partial derivatives, required control is

$$\dot{u} = \frac{g_x - f_x}{f_u} g(x)$$

The Basic Climate Model

$\Delta F = G$

$\Delta C = B F + \beta G - \sigma C$

$\Delta T = \mu \ln (1 + C / C_1) - \alpha T$

Greenhouse gas emissions *G*
Cumulative emissions *F*
Atmospheric concentrations *C*
Global mean temperature *T*

C_1 = 280 ppmv and T_1 = 14.6 °C denote preindustrial levels

$\mu = Q_{2C} / (c_{oc} \ln 2)$, $\alpha = Q_{2C} / (c_{oc} T_{2C})$

Q_{2C} = 3.7 W m^{-2} radiative forcing for doubling concentration

c_{oc} = 61.4 Wa m^{-2} $°C^{-1}$: effective ocean heat capacity

$T_{2C} \in$ [1.5°C, 4.5°C] climate sensitivity (double concentration)

Parameter	Value	Initial condition	Value
B	$1.51 \cdot 10^{-3}$ ppm/(Gt C $\cdot a$)	G_0	7.9 Gt C/a
β	0.47 ppm/(Gt C)	F_0	426 Gt C
σ	$2.15 \cdot 10^{-2}$ 1/a	C_0	360 ppm
μ	$8.7 \cdot 10^{-2}$ °C/a	T_0	15.3 °C
α	$1.7 \cdot 10^{-2}$ 1/a		

Source: Hasselmann etal 1997, Petschel-Held etal 1999, Kriegler/Bruckner 2004

Temperature Limits and Admissible Emission Paths for CO2 Stabilization

Stabilize atmospheric carbon at limit C^* with function $h(C) = \omega(C^* - C)$

$$\dot{C} = BF + \beta G - \sigma C = \omega(C^* - C) = h(C).$$

Carbon limit is function of equilibrium temperature T^* and climate sensitivity T_{2C}

$$C^* = C_1(2^{\Theta} - 1)$$

where $\Theta = T^*/T_{2C}$

Enforced concentration path: $$C(t) = C^0 + (C^* - C^0)(1 - e^{-\omega t})$$

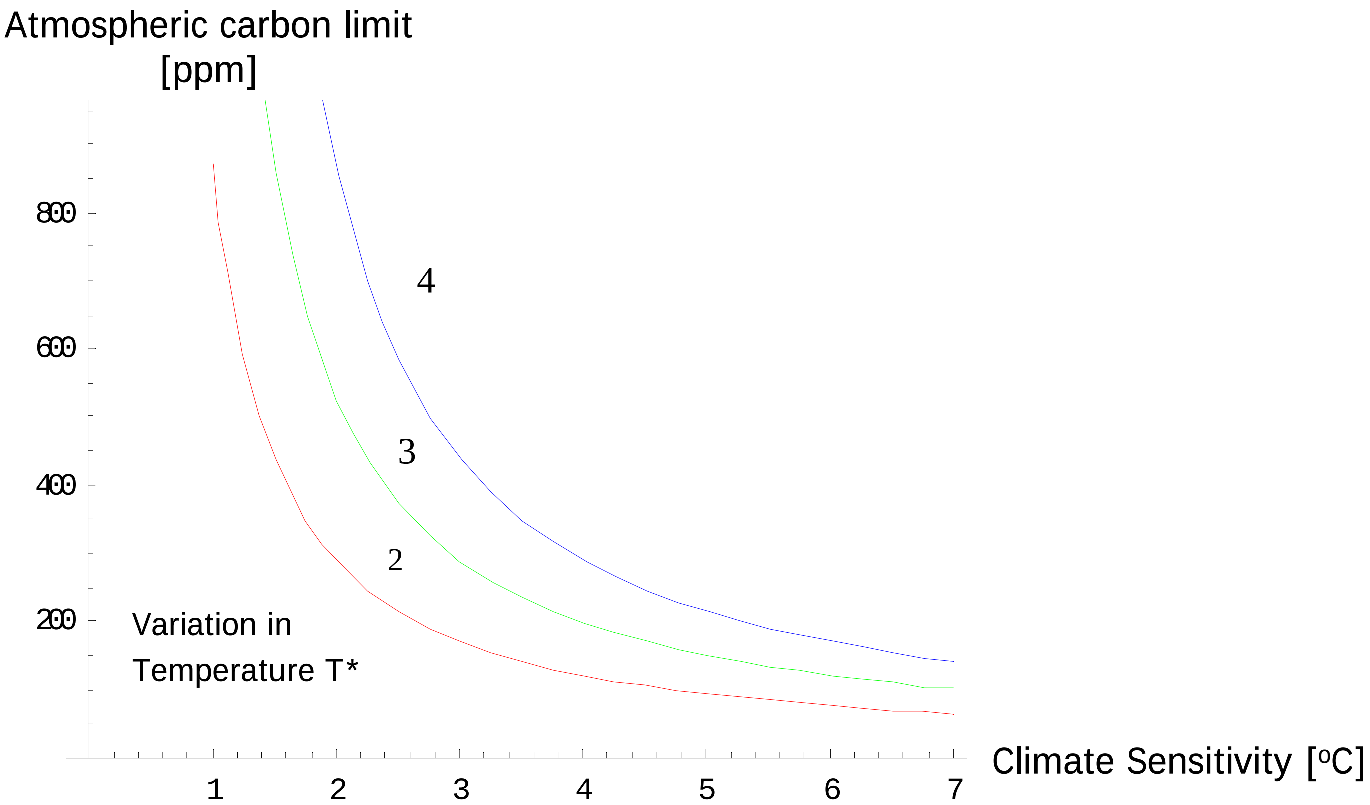
Constraint on emission change $$\beta \dot{G} = -BG + \omega(\sigma - \omega)(C^* - C^0)e^{-\omega t}$$

Controlled emissions path $$G(t) = G^0 e^{-bt} + \bar{G}(e^{-bt} - e^{-\omega t})$$

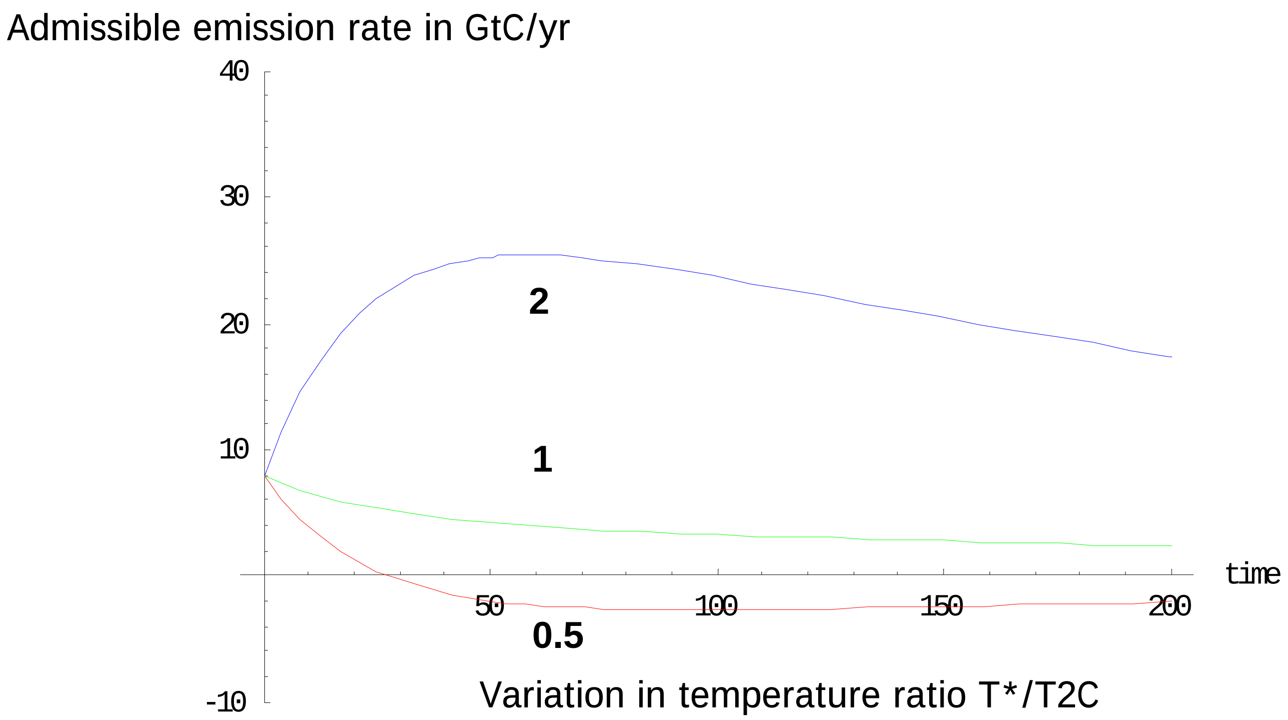
$$b = B/\beta \qquad \bar{G} = \frac{\omega(\sigma - \omega)(C^* - C^0)}{\beta\omega - B}.$$

Carbon and Temperature Limits and Climate Sensitivity

Temperature limit $\Delta T(t) \leq w\,(T^*(t^*) - T(t))$, $T(t) = T^* - (T^* - T^0)\,e^{-wt}$

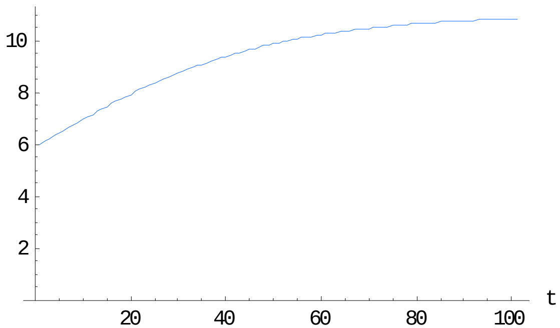


Admissible Emission Range for Variation of Temperature Limits

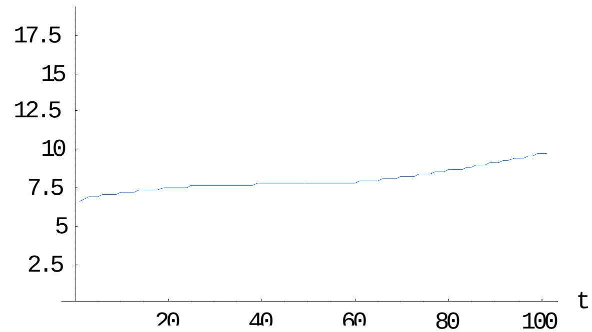


Technical Change and Climate Damage

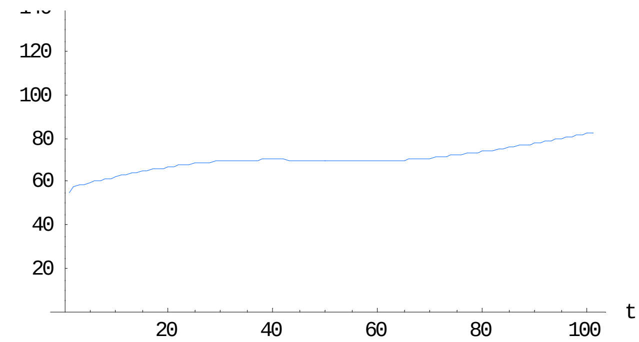
Population in bio.



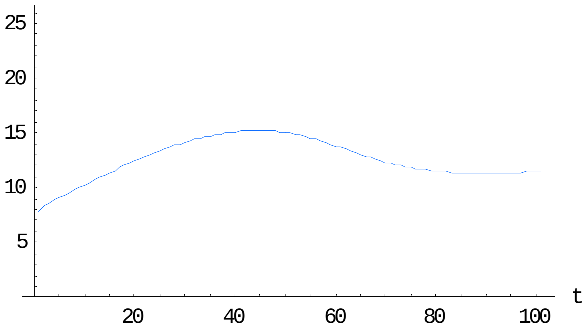
Production/capita in $10,000



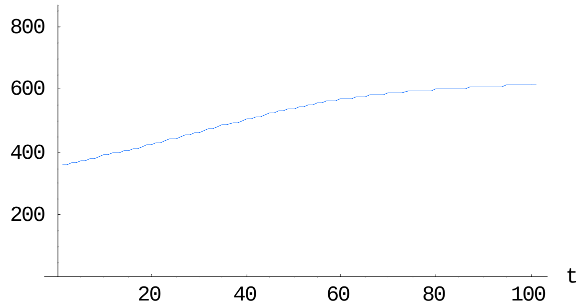
Energy/capita in GJ



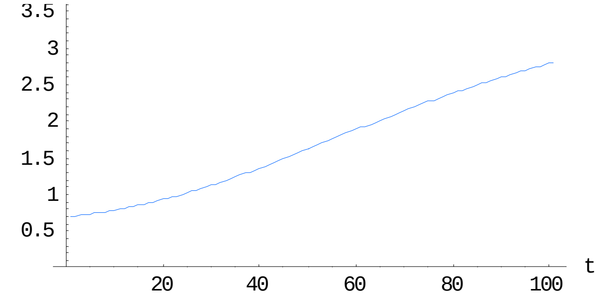
Emissions in GtC/a



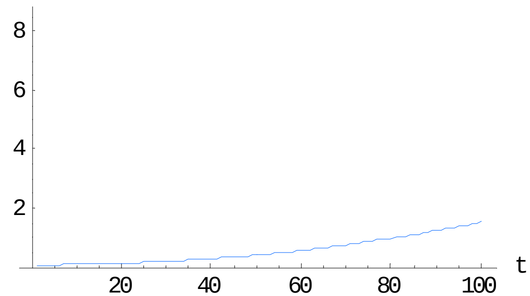
Atmospheric carbon in ppm



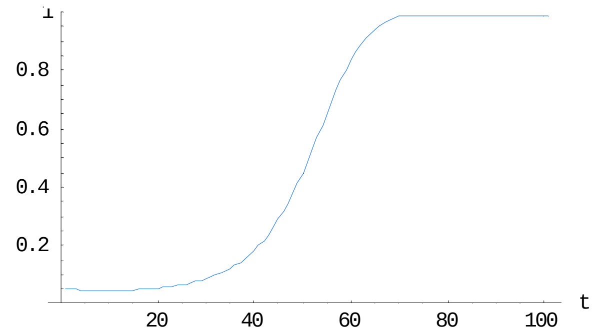
Temperature change in ^{o}C



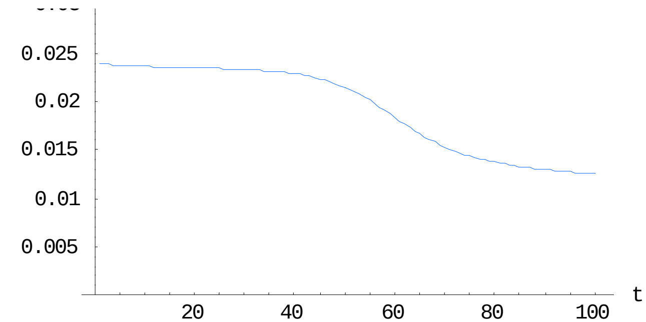
Climate damage/capita in $10,000



Allocation to low-emission energy

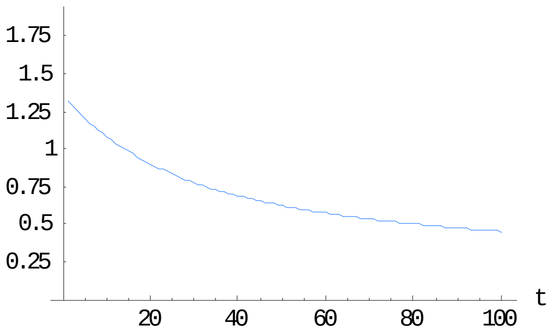


Carbon intensity of energy in GtC/EJ

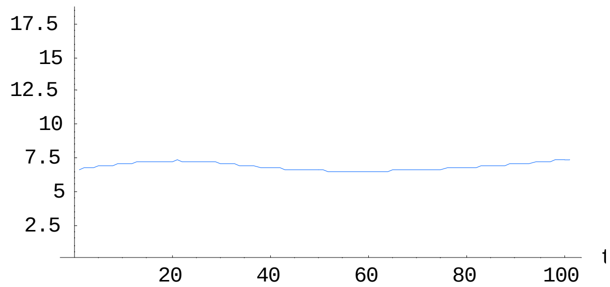


Technical Change and Adaptive Control

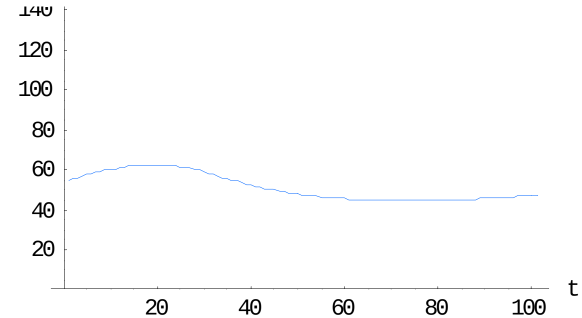
Emissions/capita in tC/cap



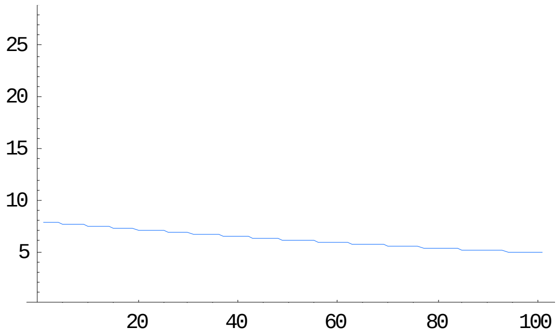
Production/capita in $10,000



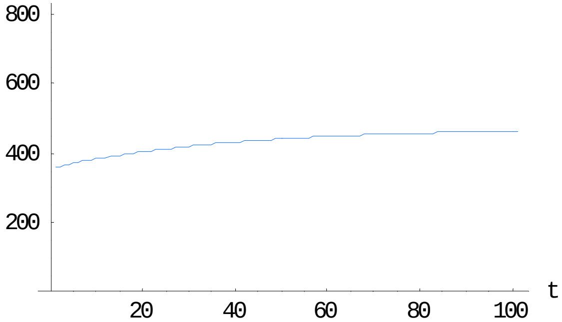
Energy/capita in GJ



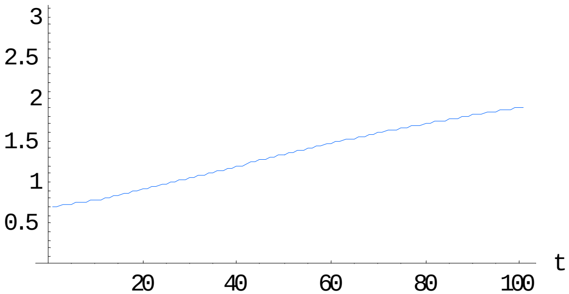
Emissions in GtC/a



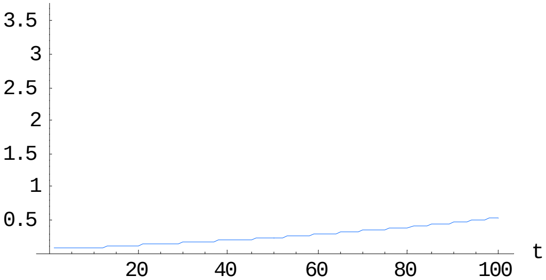
Atmospheric carbon in ppm



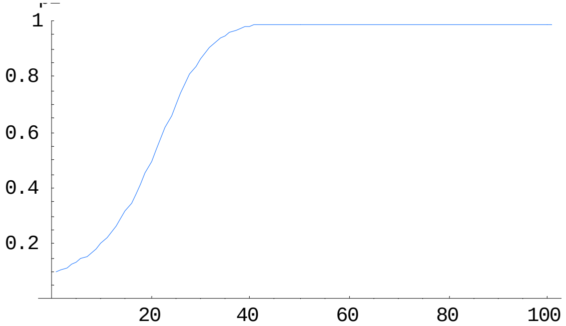
Temperature change in °C



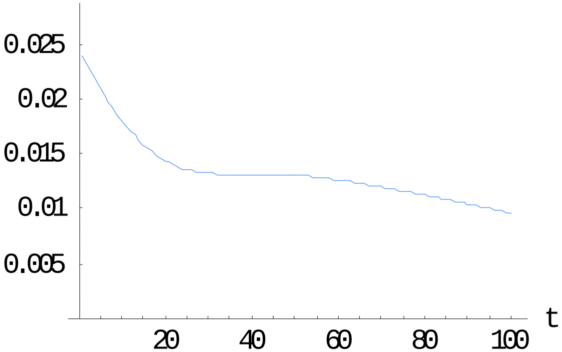
Climate damage/capita in $10,000



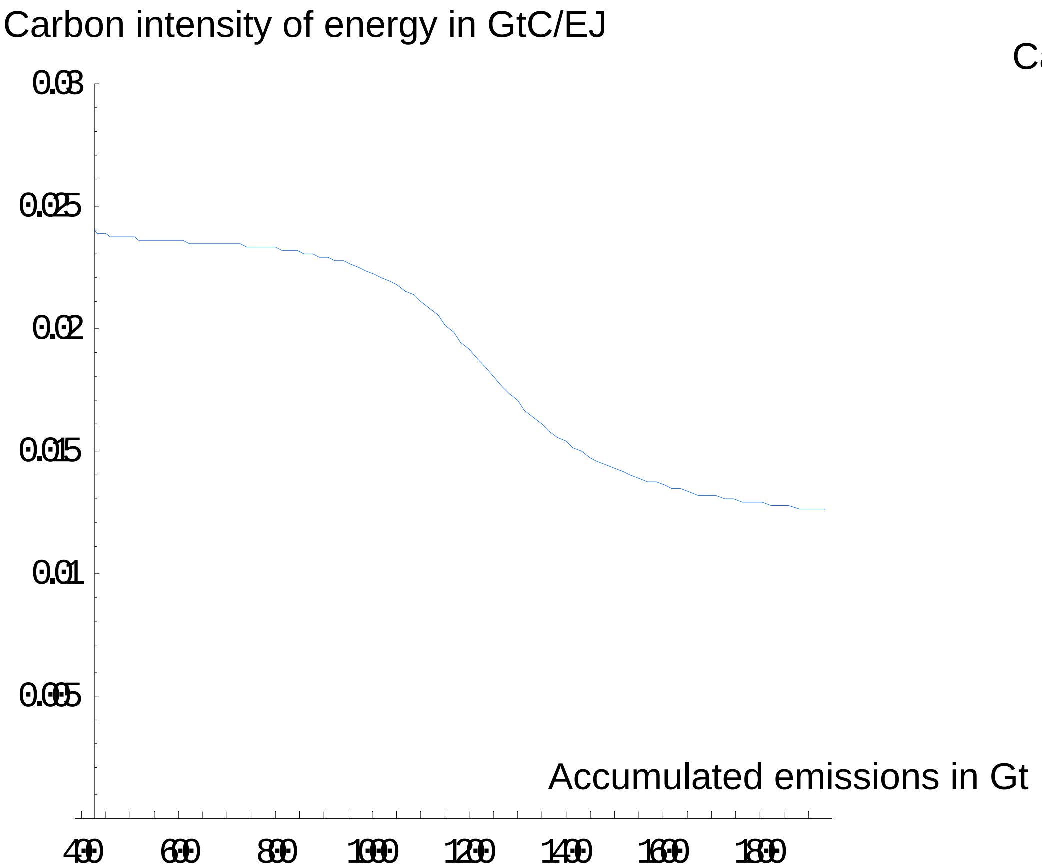
Allocation to low-emission energy



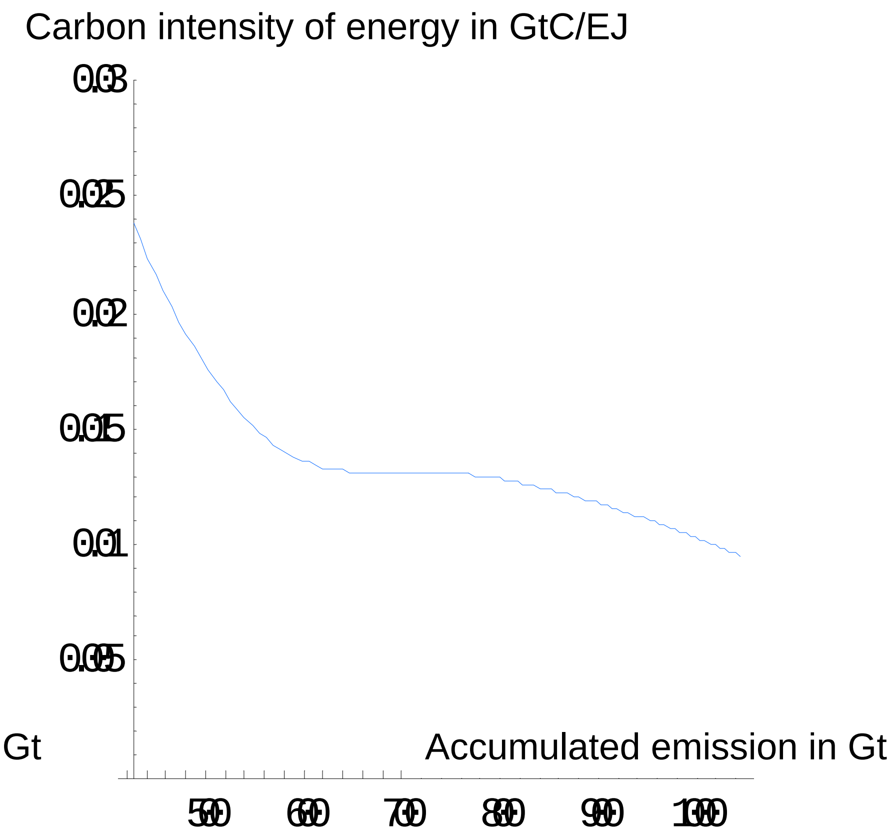
Carbon intensity of energy in GtC/EJ



Carbon Intensity vs. Accumulated Emissions

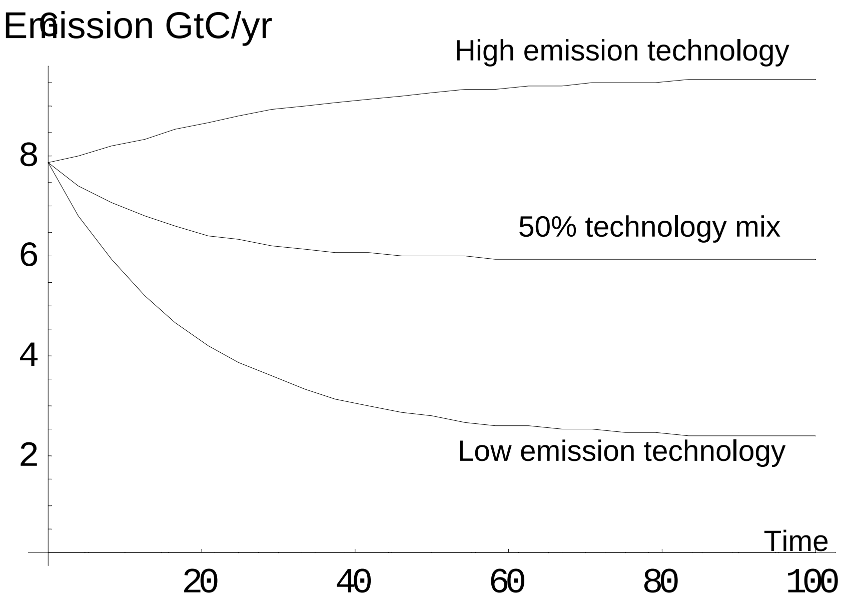


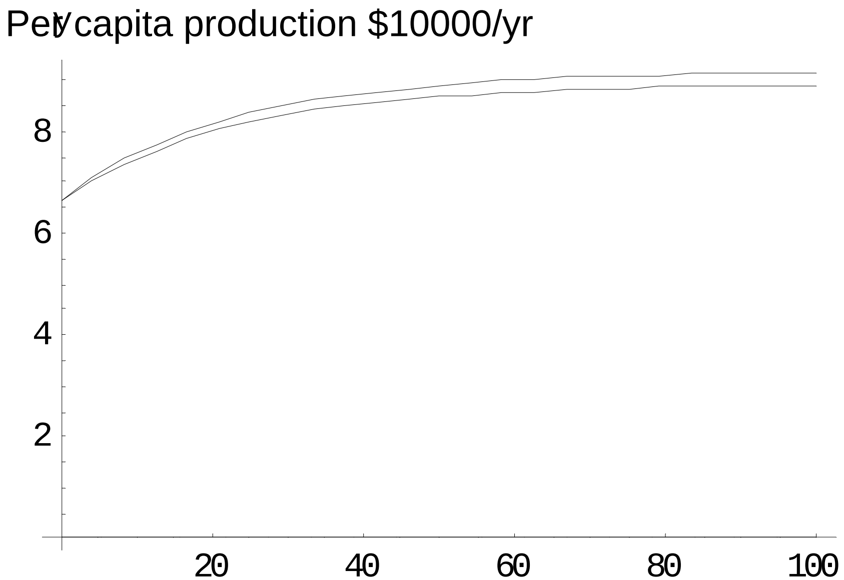
Climate damage optimal control

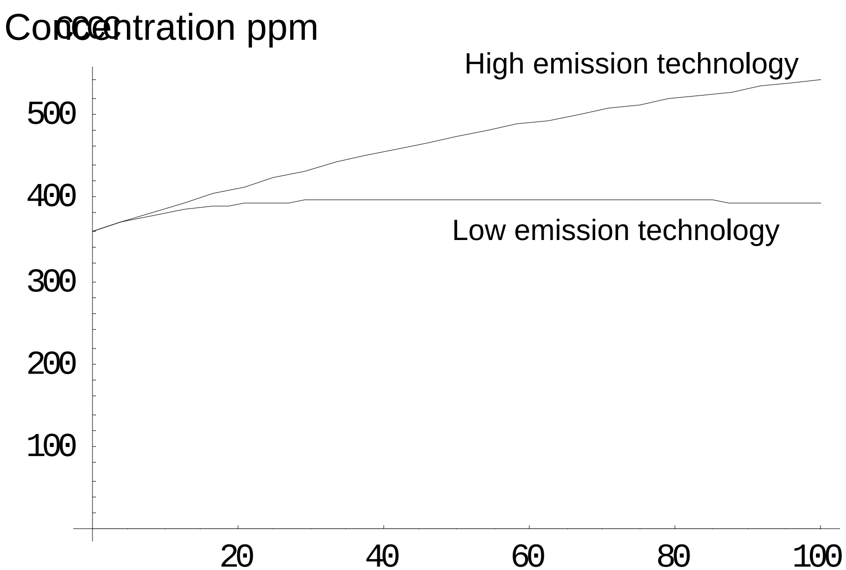


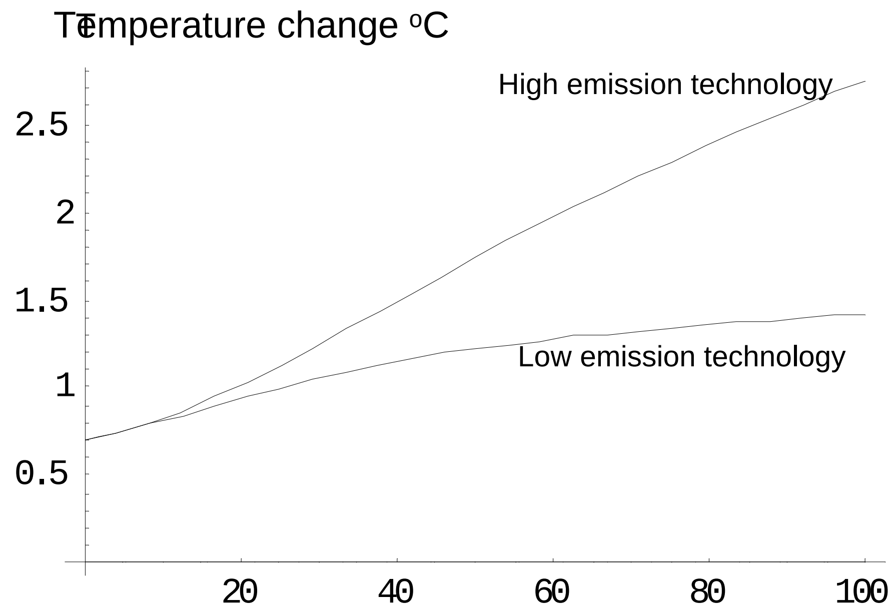
Adaptive control

Comparison of Technology Paths

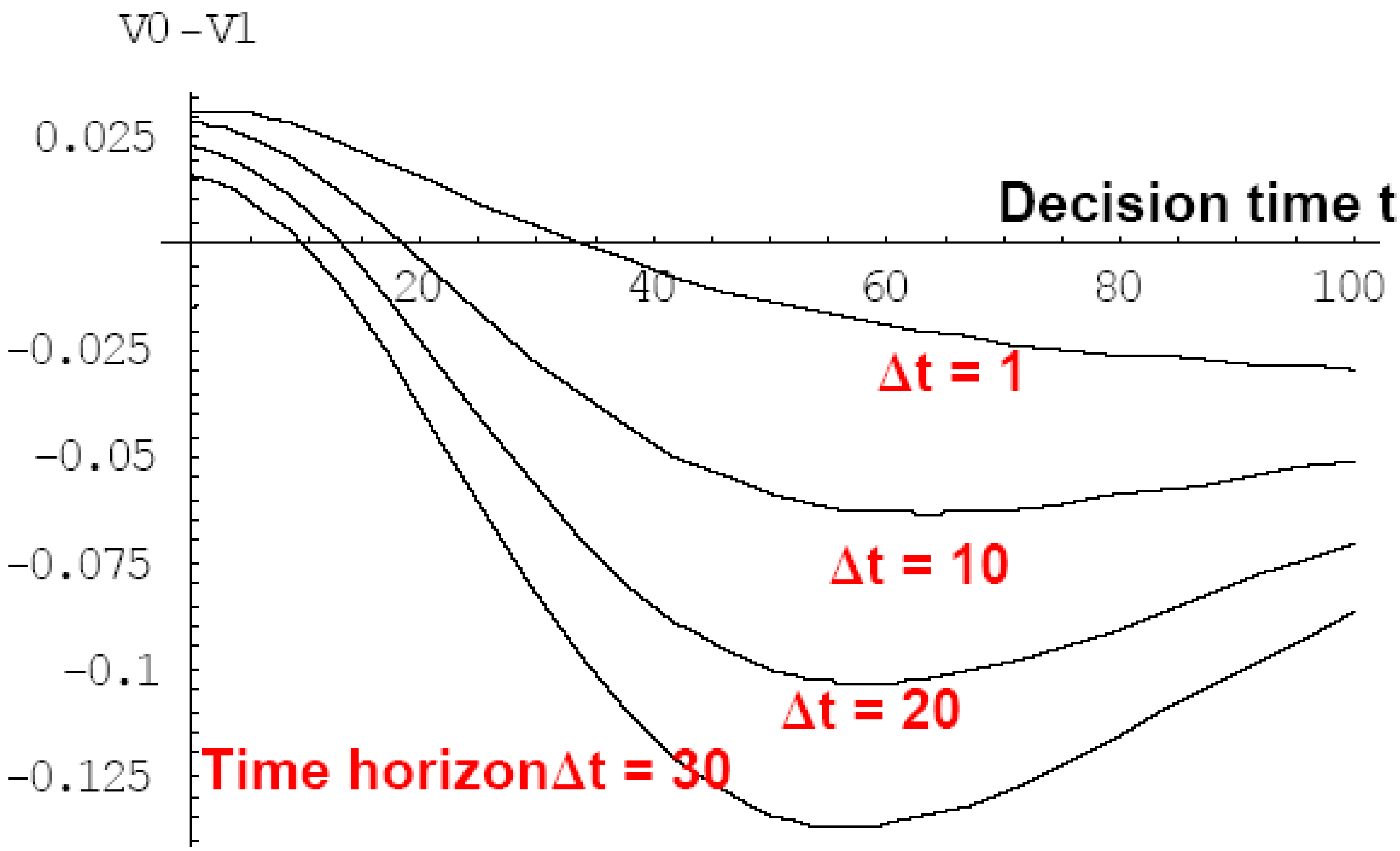






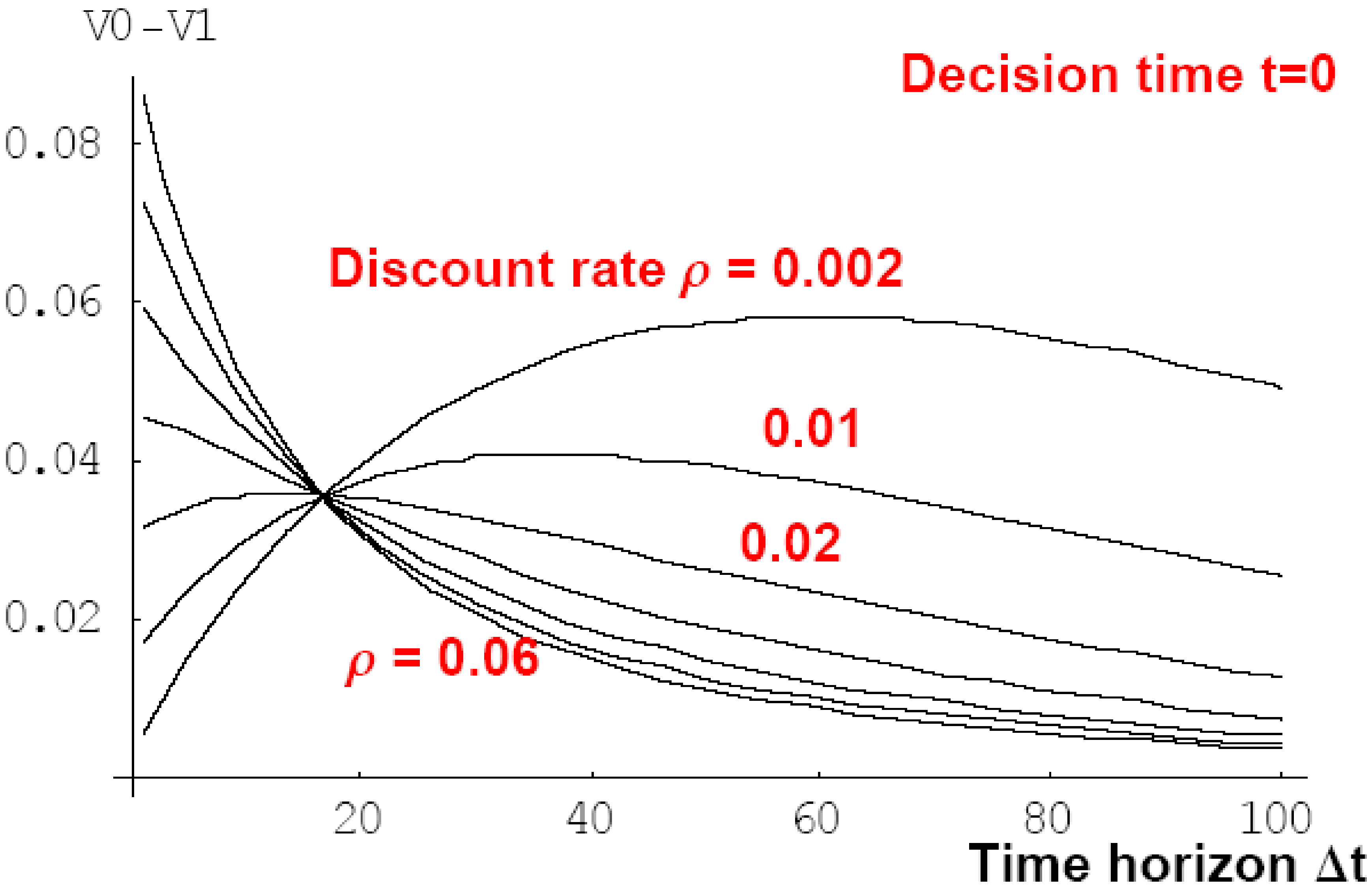


Value Difference High- vs Low-Emission Technology
for Changing Time Horizon



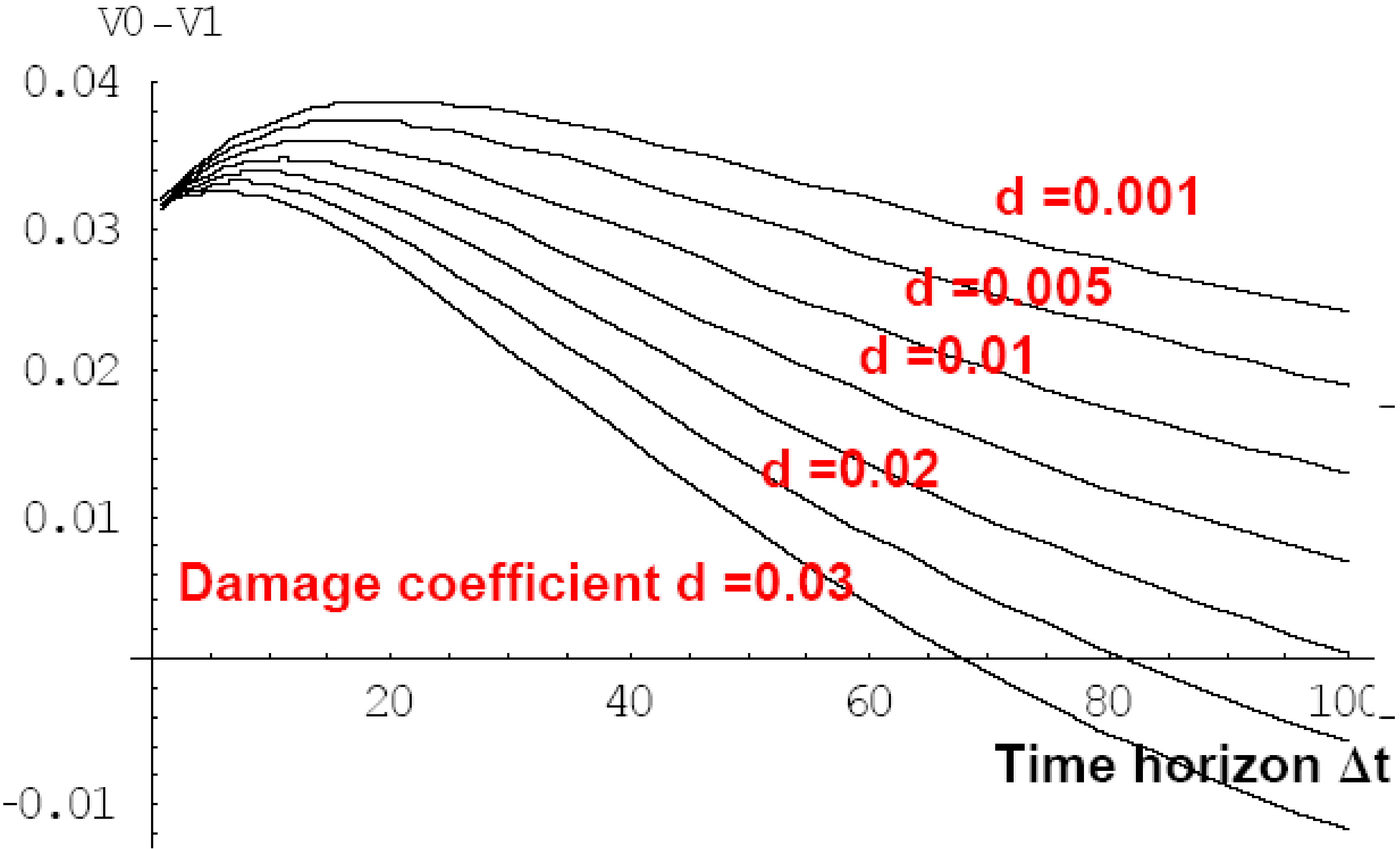
Value Difference High- vs Low-Emission Technology

for Changing Discount rate



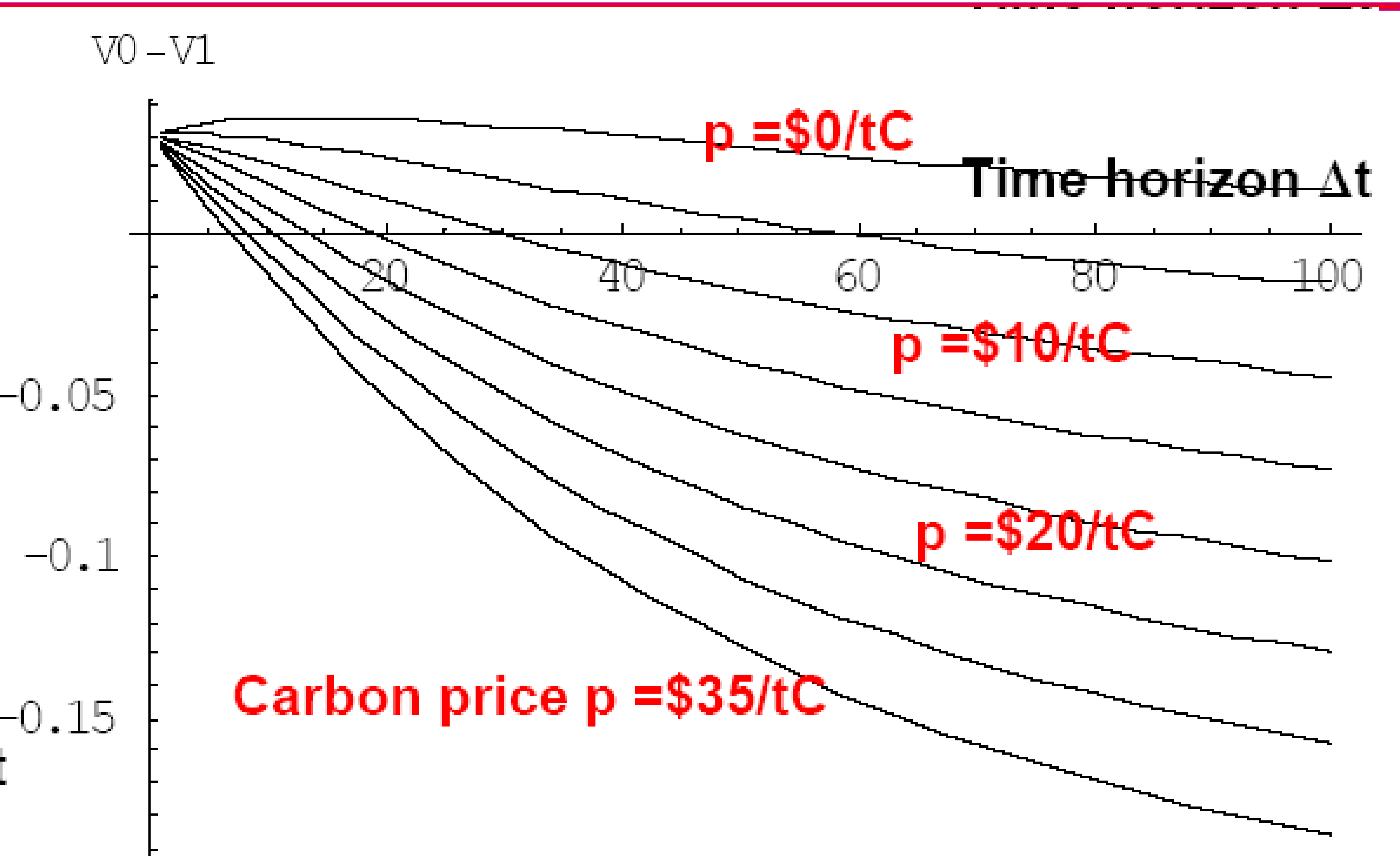
Value Difference High- vs Low-Emission Technology

for Changing Climate Damage



Value Difference High- vs Low-Emission Technology

for Changing Carbon Price



Emission Reduction: a Global Cooperation Problem

$$G(t) = \sum_i G_i(t)(1 - r_i(t)) \leqslant G^*(t)$$

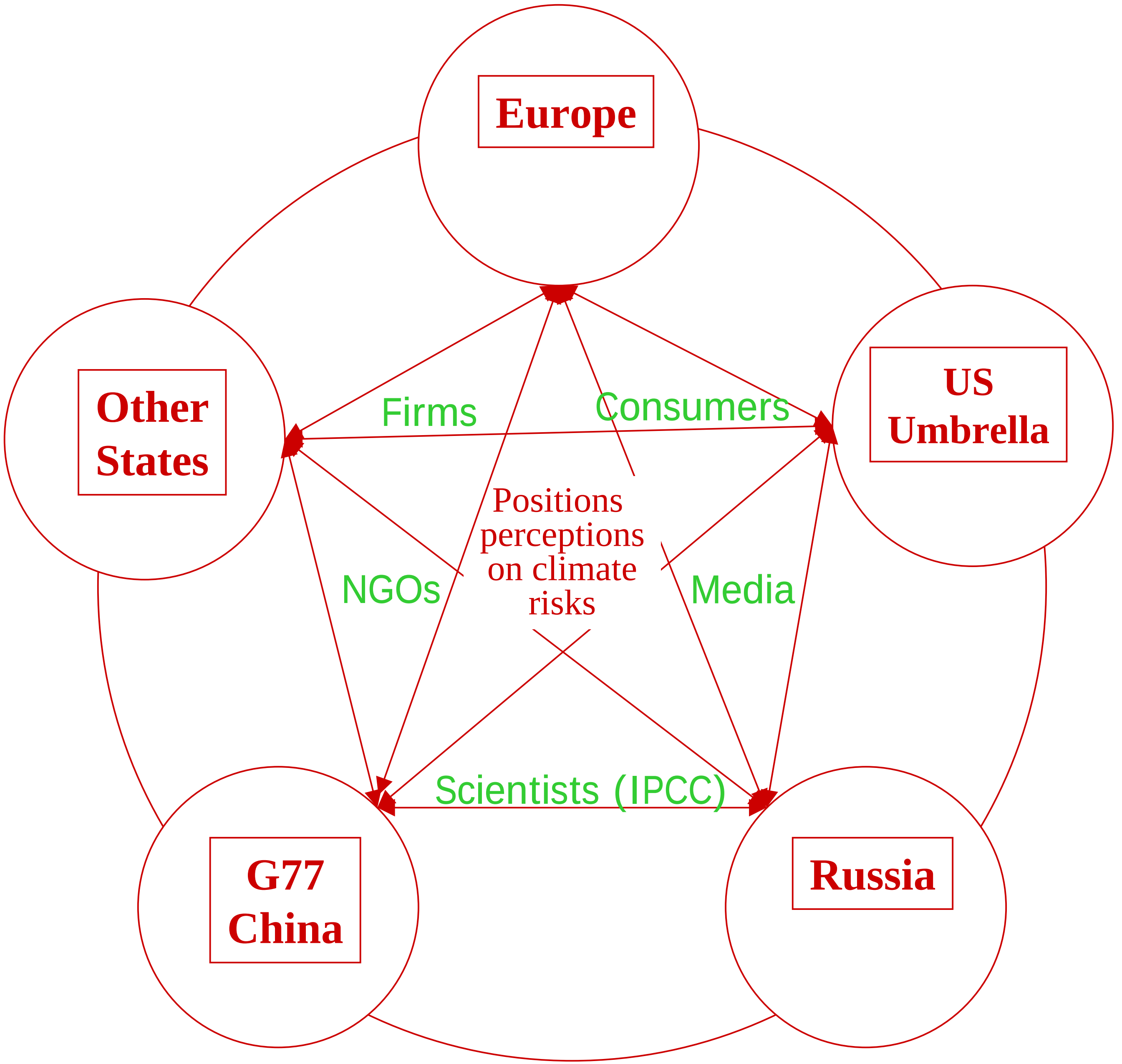
$G(t)$: Global emissions at time *t*

$G^*(t)$: Global emission target at time *t*

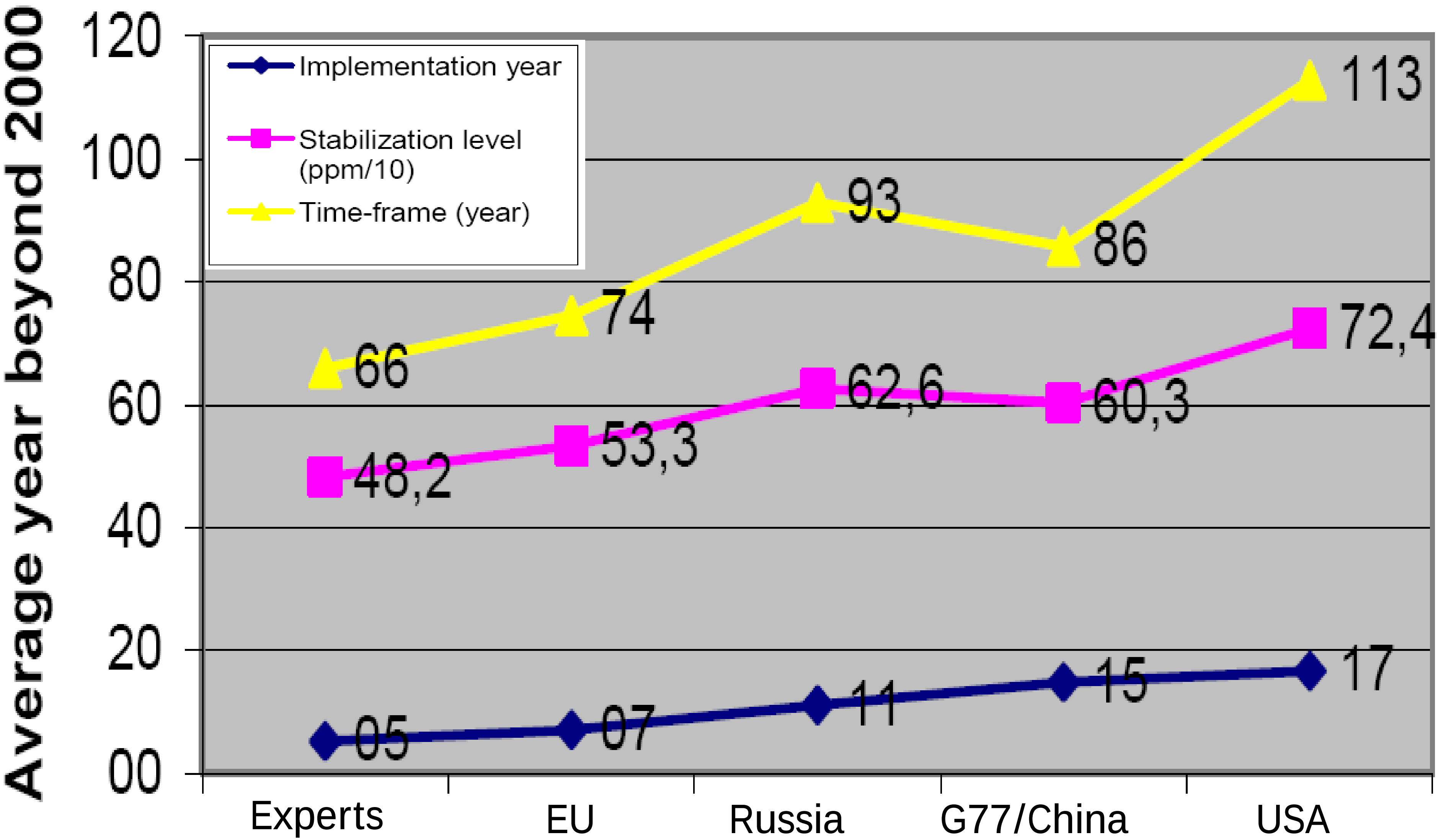
$G_i(t)$: Baseline emissions path of actor *i*

$r_i(t)$: Emission reduction of *i* from baseline

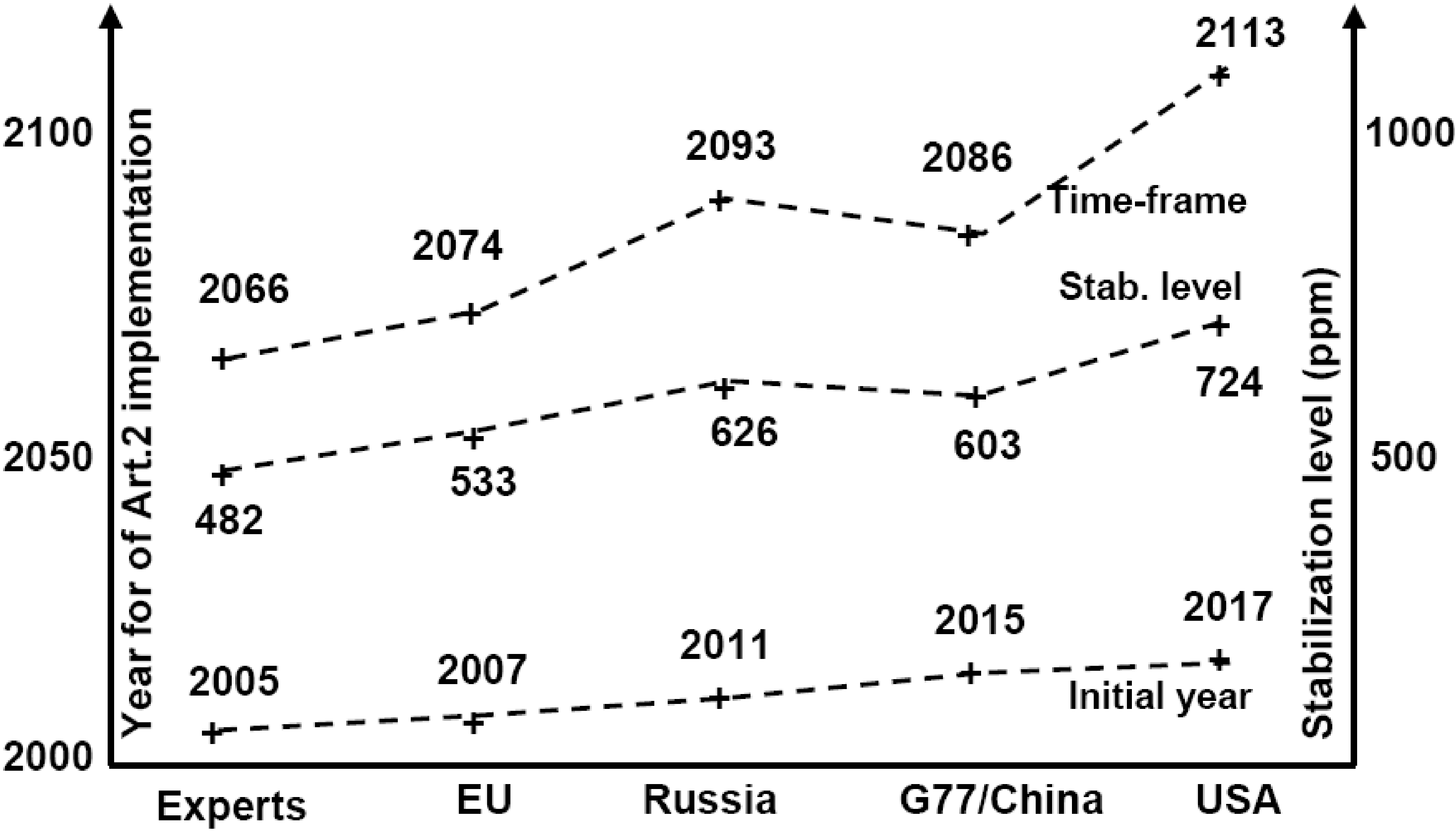
Major Actors in Climate Policy



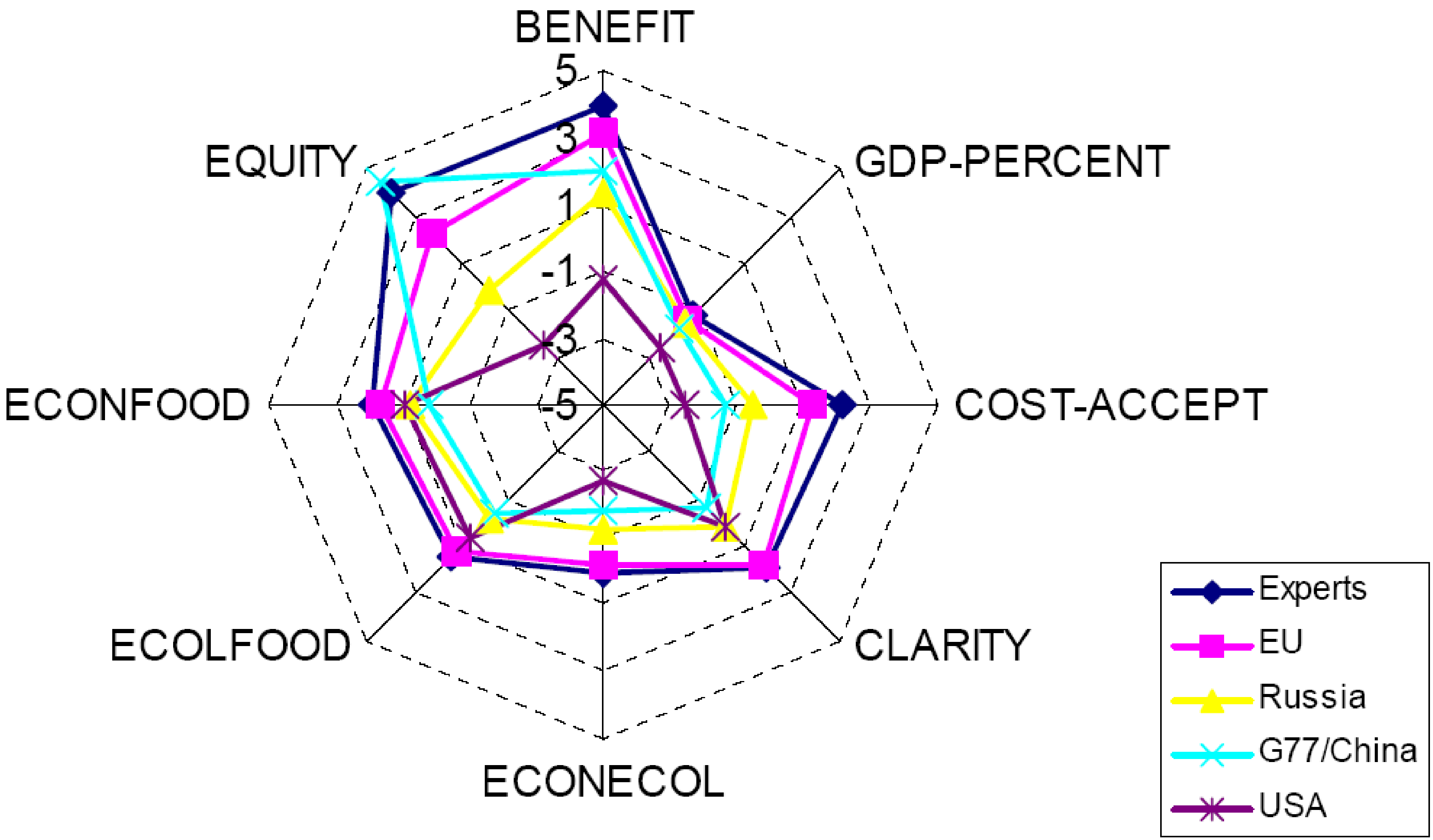
Expert Survey on Art. 2 at COP8, New Delhi 2002



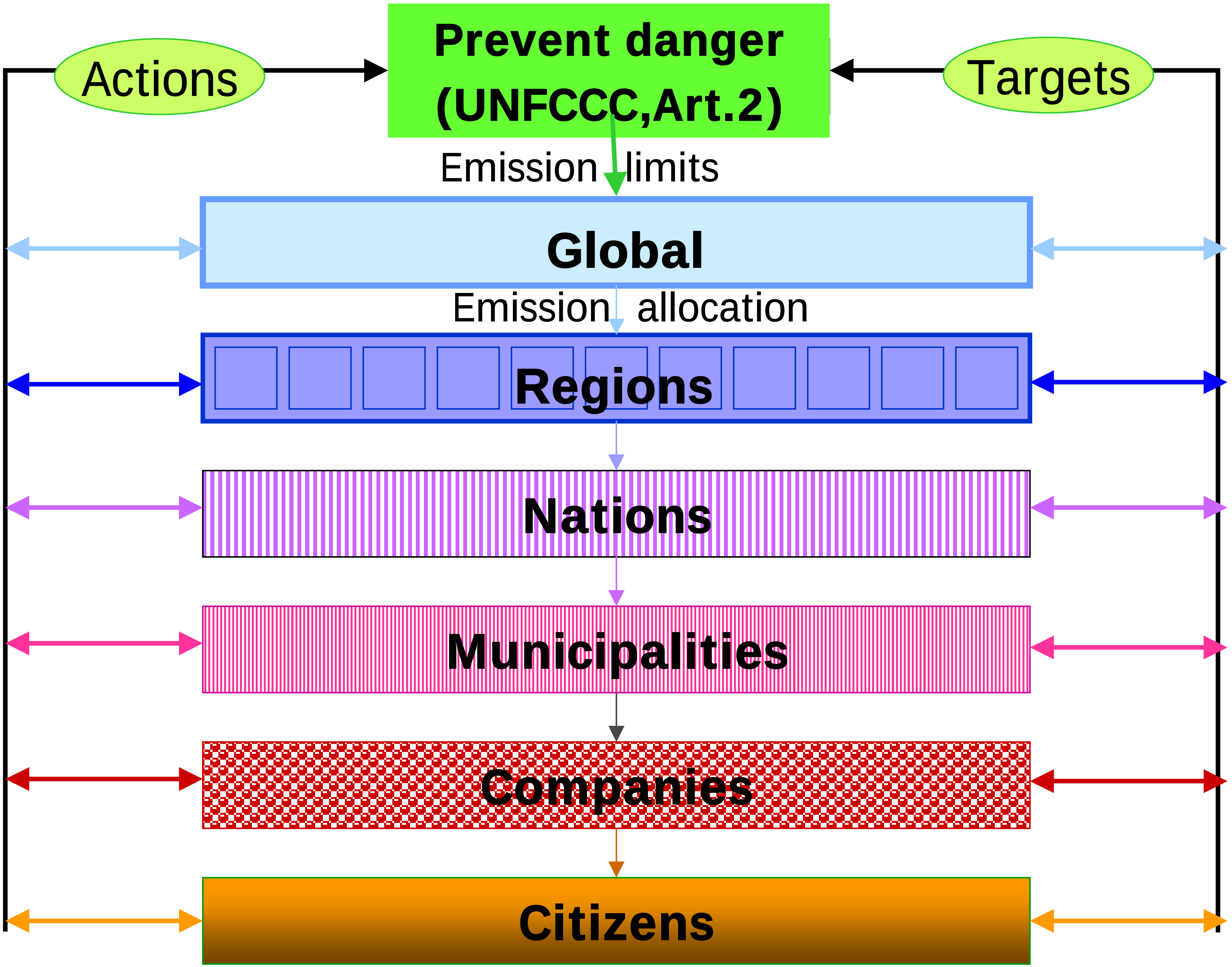
Average Positions on Stabilization
Expert Survey at COP8, New Delhi 2002



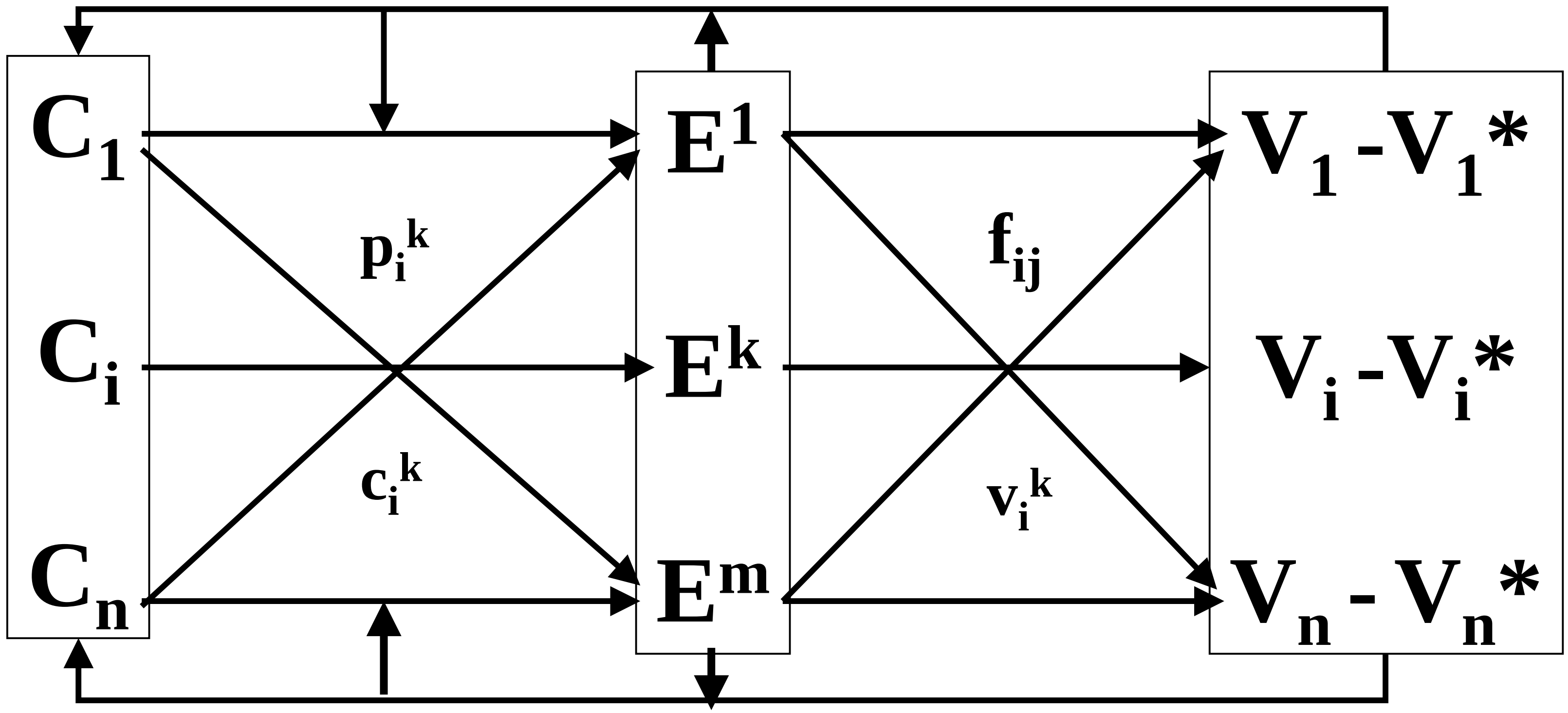
Average Actor Positions in Multi-criteria Chart



Micro-macro and Multi-level Decisionmaking

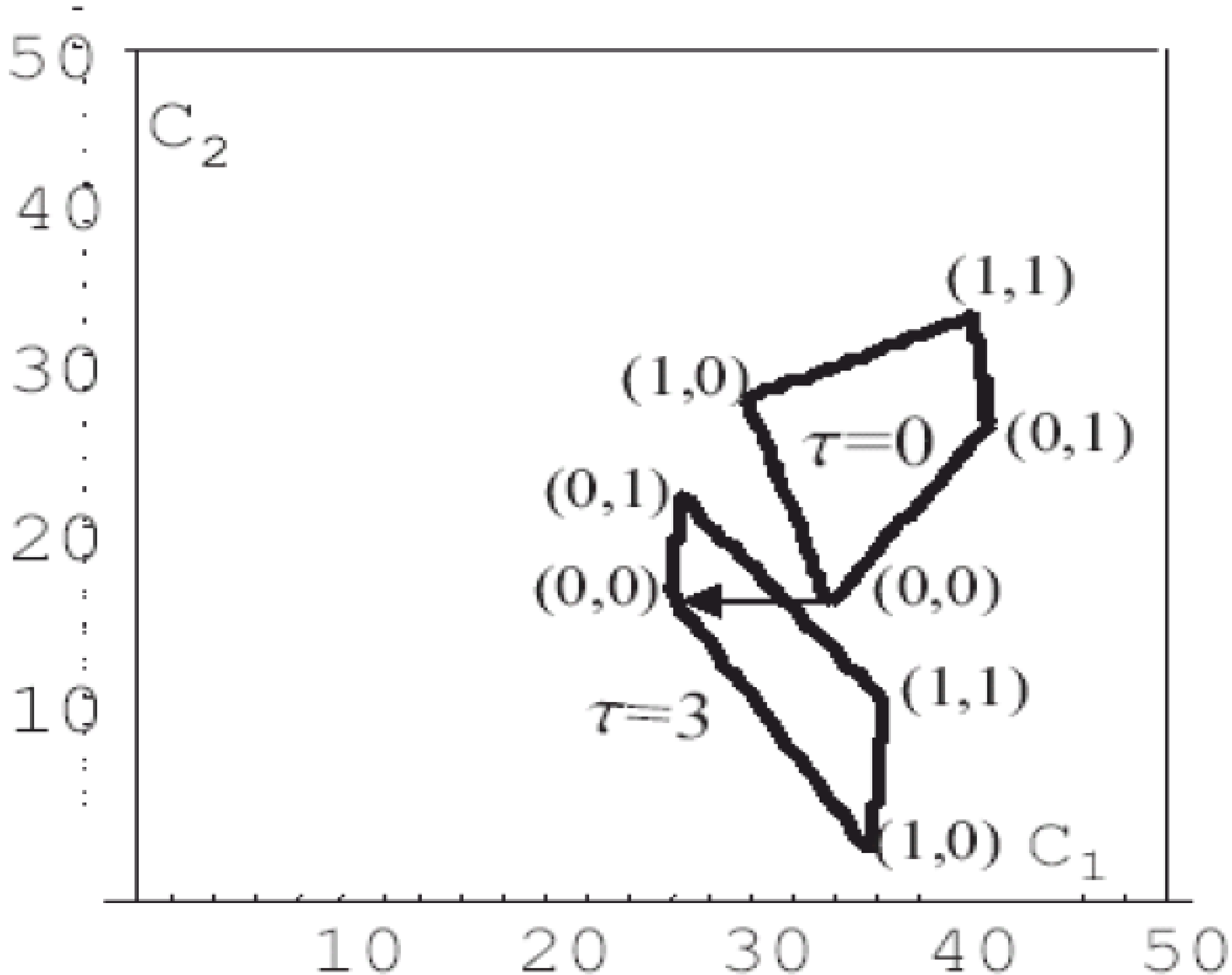


Integrated Assessment with Multiple Actors



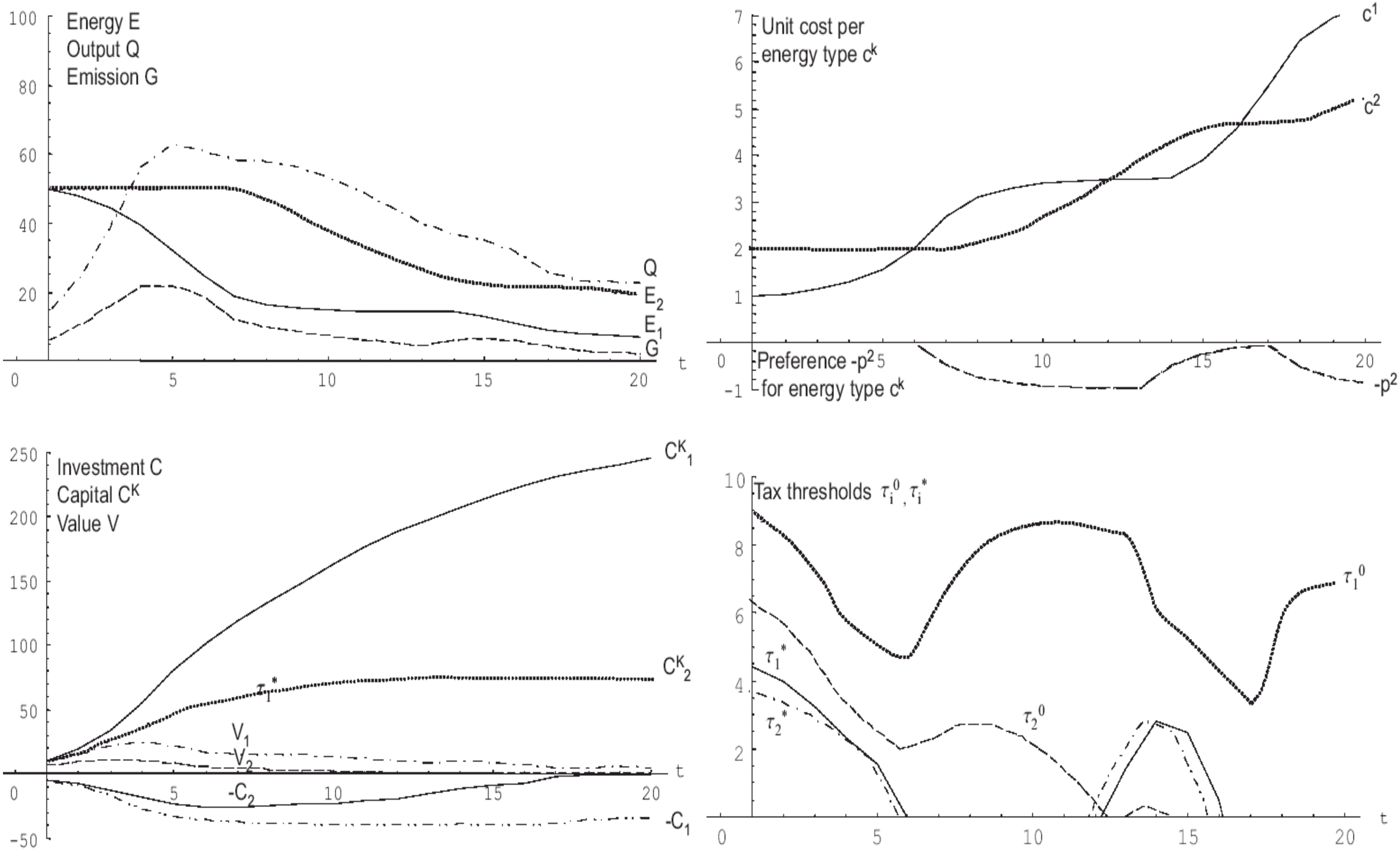
Investment	Allocation Costs Prices	Energy Systems	Efficiency Benefits Risks	Values Goals

Tax-induced Technology Switching Among Economic Competitors

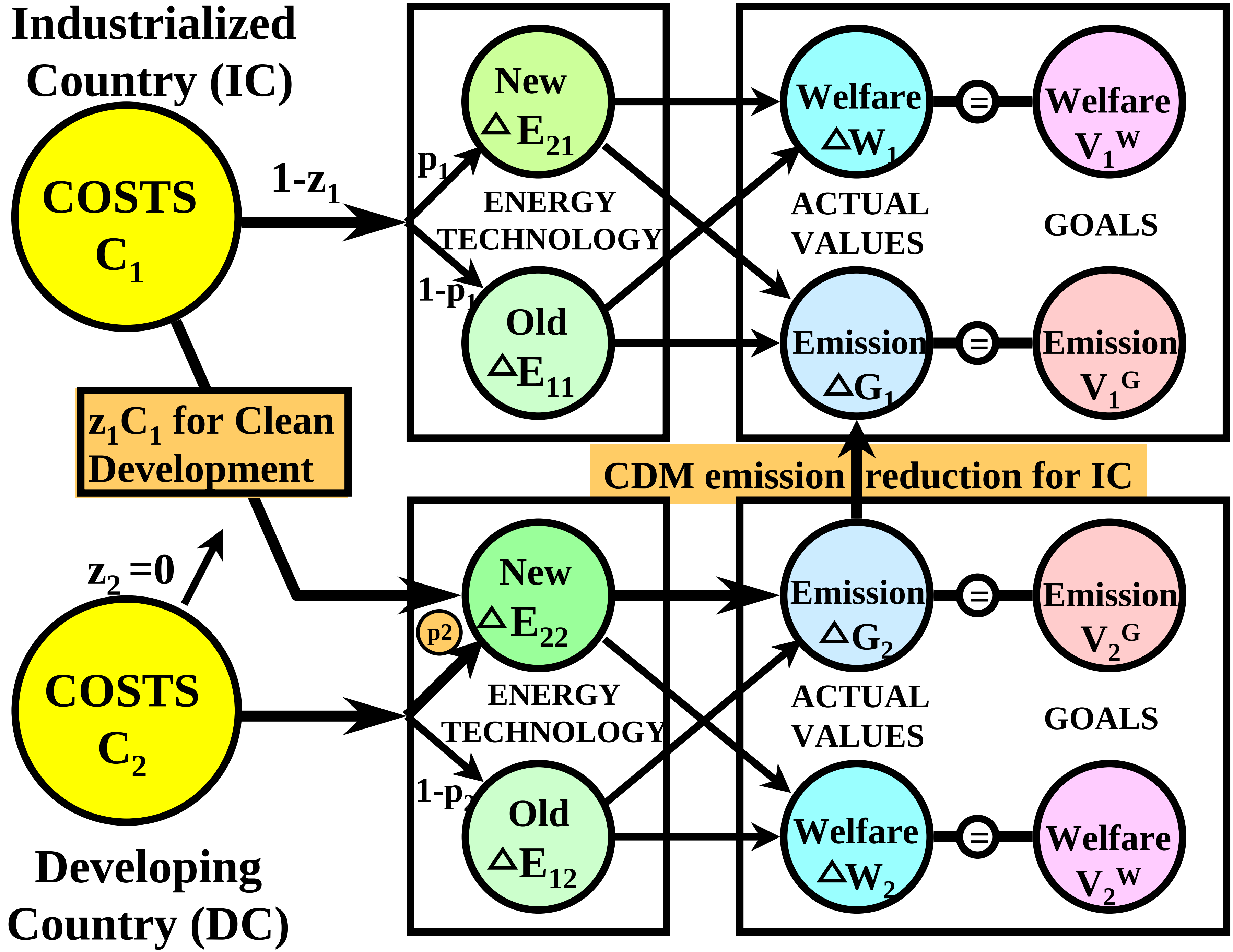


Equilibria in investment space (C1, C2) of two firms with choice between high emission technology (p=0) and low emission technology (p=1) for tax τ = 0 and τ = 3.

Competition of Two Energy Paths with Emission Tax

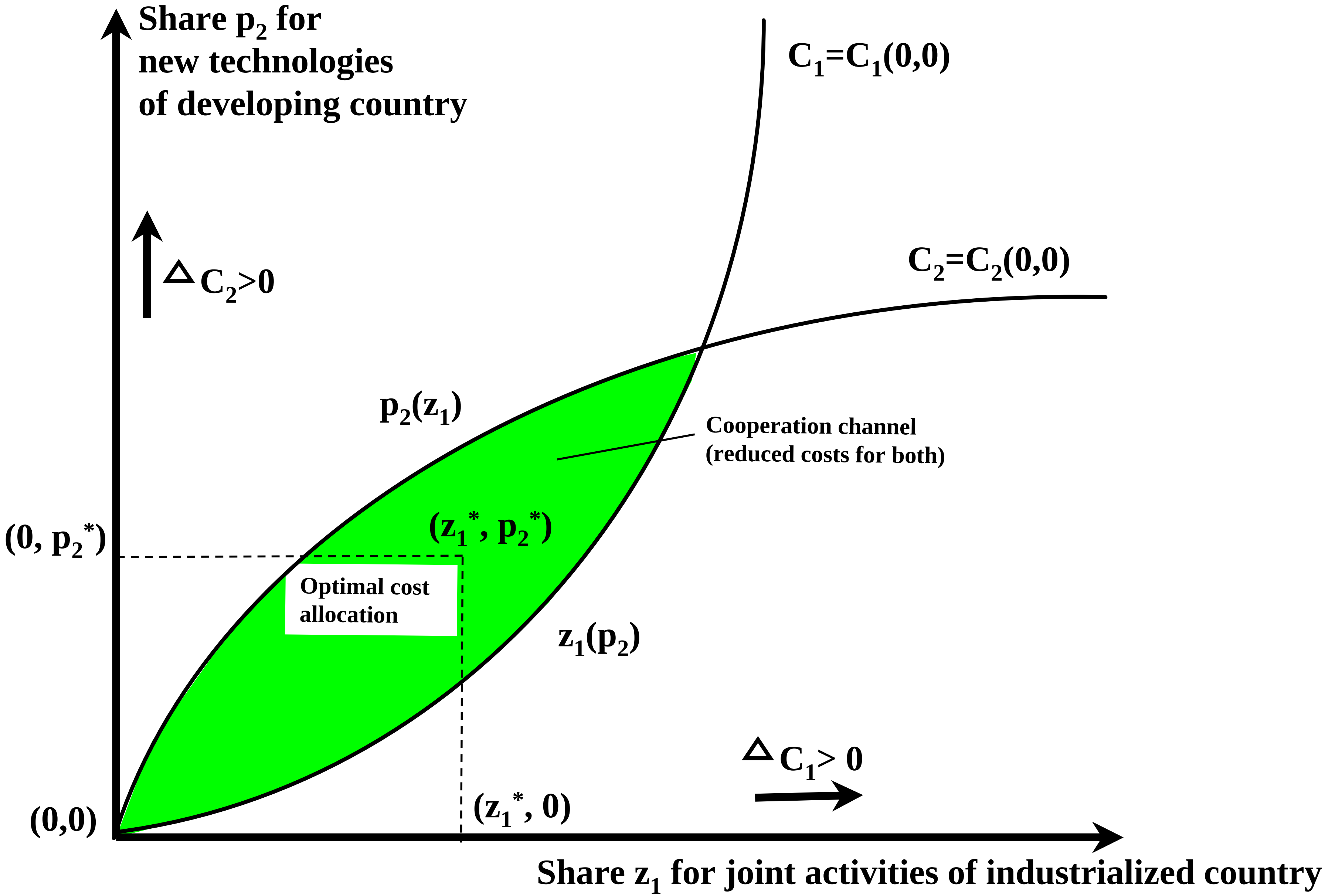


Scheffran 2002

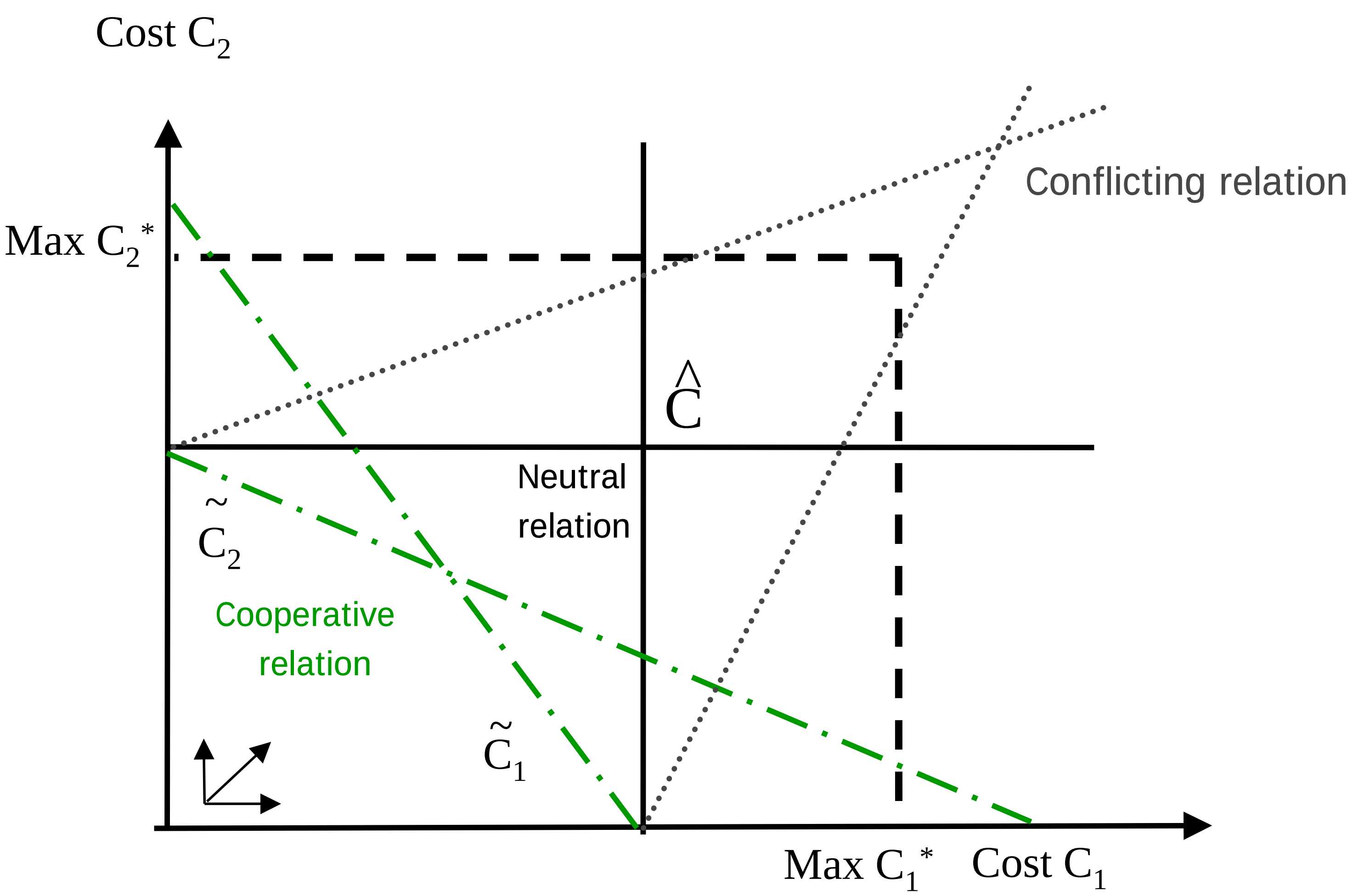


Industrialized Country (IC)
COSTS C_1
$1-z_1$
p_1
$1-p_1$
New ΔE_{21}
Old ΔE_{11}
ENERGY TECHNOLOGY
Welfare ΔW_1
Emission ΔG_1
ACTUAL VALUES
Welfare V_1^W
Emission V_1^G
GOALS
z_1C_1 for Clean Development
CDM emission reduction for IC
$z_2=0$
COSTS C_2
p2
$1-p_2$
New ΔE_{22}
Old ΔE_{12}
ENERGY TECHNOLOGY
Emission ΔG_2
Welfare ΔW_2
ACTUAL VALUES
Emission V_2^G
Welfare V_2^W
GOALS
Developing Country (DC)

Cooperation Channel for Low Emission Technology



Conflict vs. Cooperation



$$\text{Taget cost } \tilde{C}_i = (\Delta V_i^* - f_{ij}\, C_j) / f_{ii}$$

Model Specifications of Multi-regional Emissions Trading

Regions

AFR Sub-Saharan Africa

CPA China, Mongolia, Vietnam, Cambodia, Laos

EEU Eastern Europe

FSU Former Soviet Union

LAM Latin America, Caribbean

MEA Middle East,North Africa

NAM North America

PAO Pacific OECD (Japan, Australia, New Zealand)

PAS Other Pacific Asia

SAS South Asia (India)

WEU Western Europe

Parameter settings

GDP and emission data of 2005 (ICLIPS ref.)

Exponents: production/costs $\alpha = \gamma = 1{,}5$

Damage: $\delta = 2$

Mitigation cost: 5% reduction, 2% GDP loss

Scenarios

BAU - Business as usual (emission baseline ICLIPS)

epc - equal per capita

10% red. - 10% reduction of 2005 baseline level (only ICs)

stabilis. - stabilisation of emissions on 1990 levels

Emission Trading: Multi-actor Dynamic Game

Incremental value of firm for emission reduction ri

$$\frac{\partial V_i}{\partial r_i} = (-u_i + 2d_i G - 2c_i r_i \bar{G}_i + \pi)\bar{G}_i - \pi_i'(\bar{G}_i(1 - r_i) - G_i^*) \geq 0.$$

Emission trading price

$$\pi = \frac{\sum_i \pi_i^*}{n} = \frac{\sum_i u_i + 2c_i r_i \bar{G}_i - 2d_i G}{n}.$$

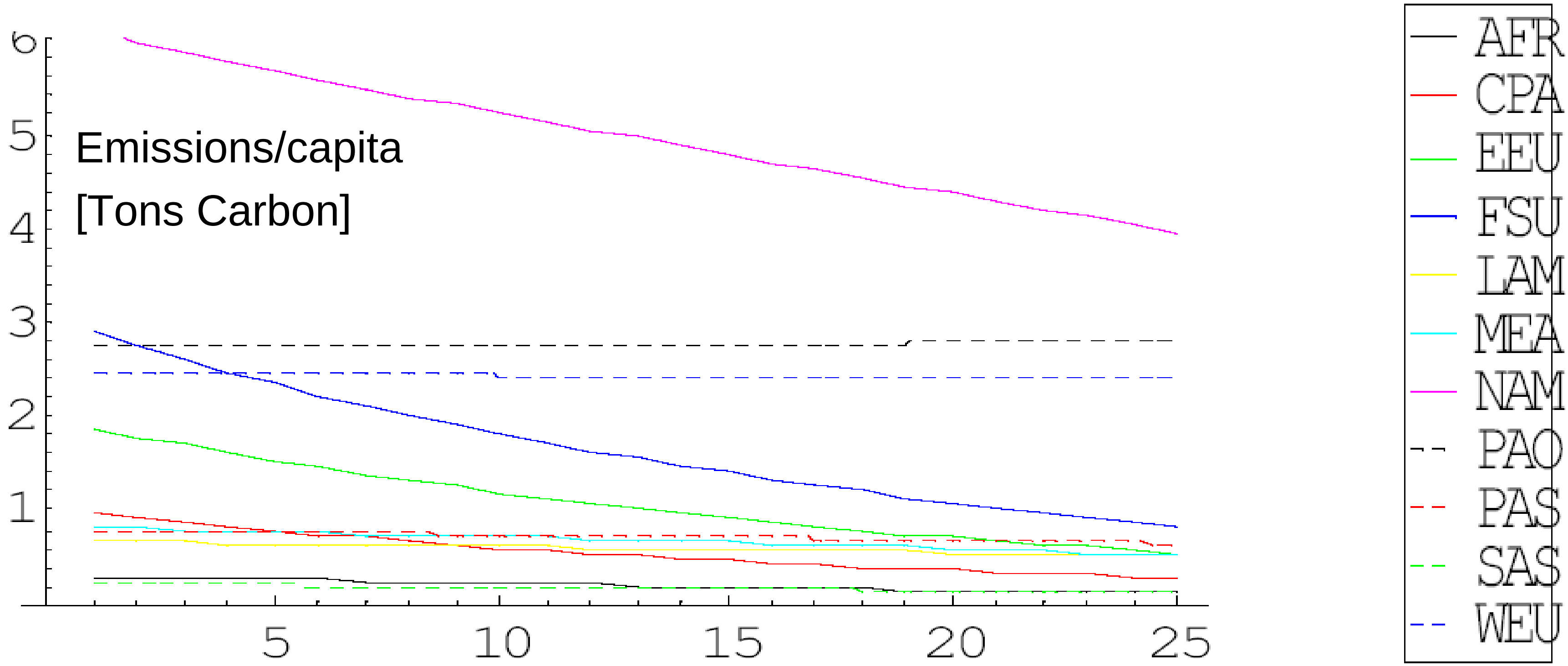
Optimal emission reduction

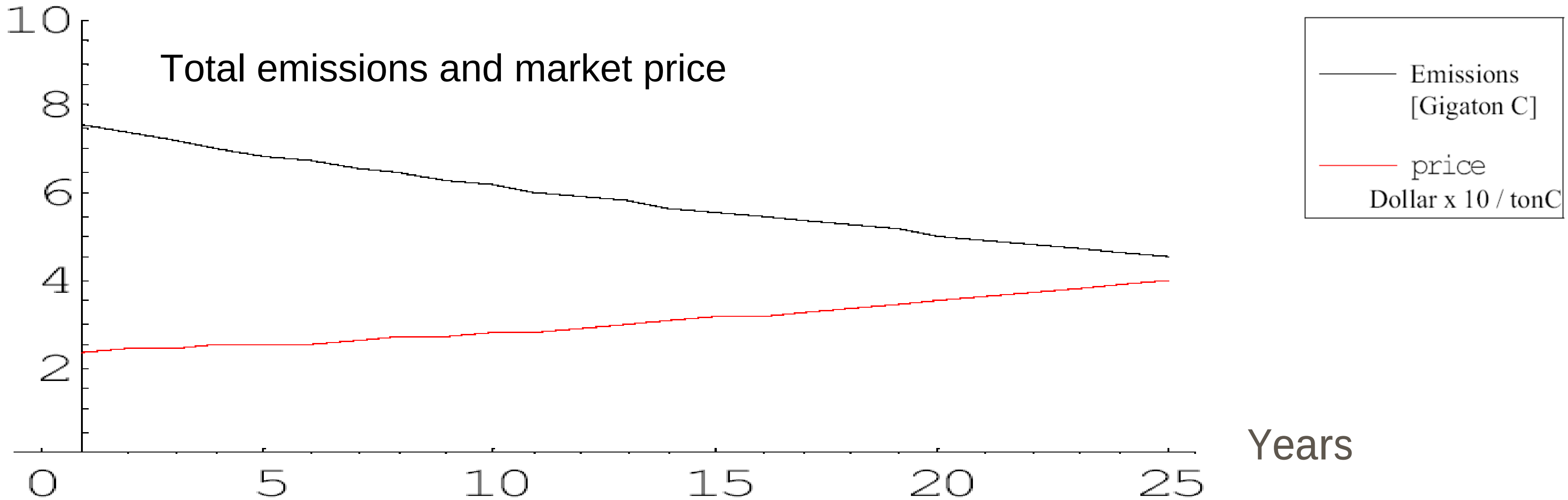
$$r_i^* = \frac{\sum_{j \neq i} \pi_j^* + u_i - 2d\bar{G}_i - n(u_i - 2d_i(\bar{G}_i + G_{-i})) + 2(G_i^* - \bar{G}_i)(c_i + d)}{2\bar{G}_i[(n-1)(d_i + c_i) - d_{-i}]}$$

$$\frac{\partial r_i^*}{\partial r_j} = \frac{2\bar{G}_j(c_j + d_{-i} - nd_i)}{2\bar{G}_i[(n-1)(d_i + c_i) - d_{-i}]}.$$

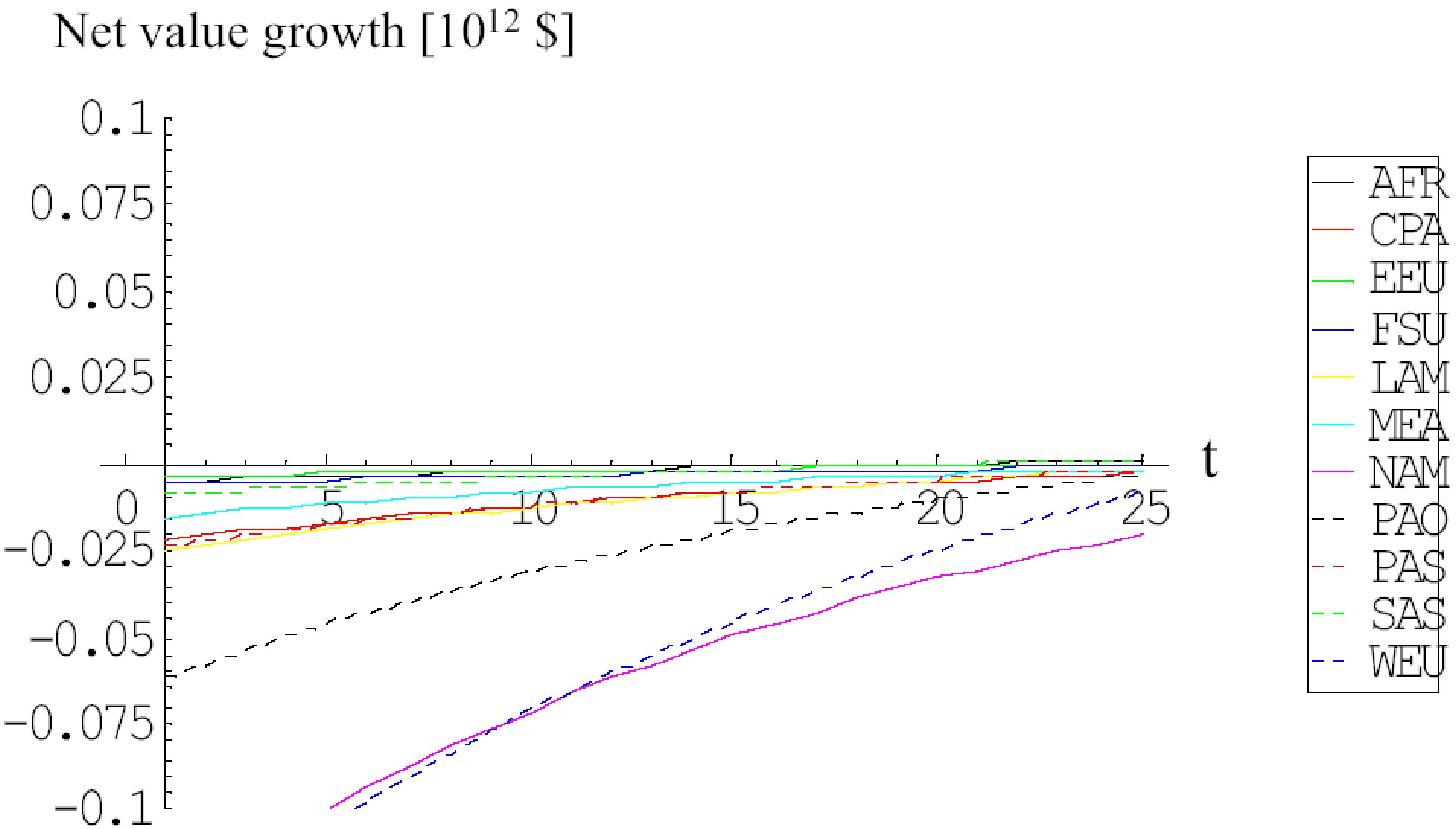
→ Coupled multi-player dynamics of emission reduction and permit price

Simulation of Emission Tradings Among 11 World Regions

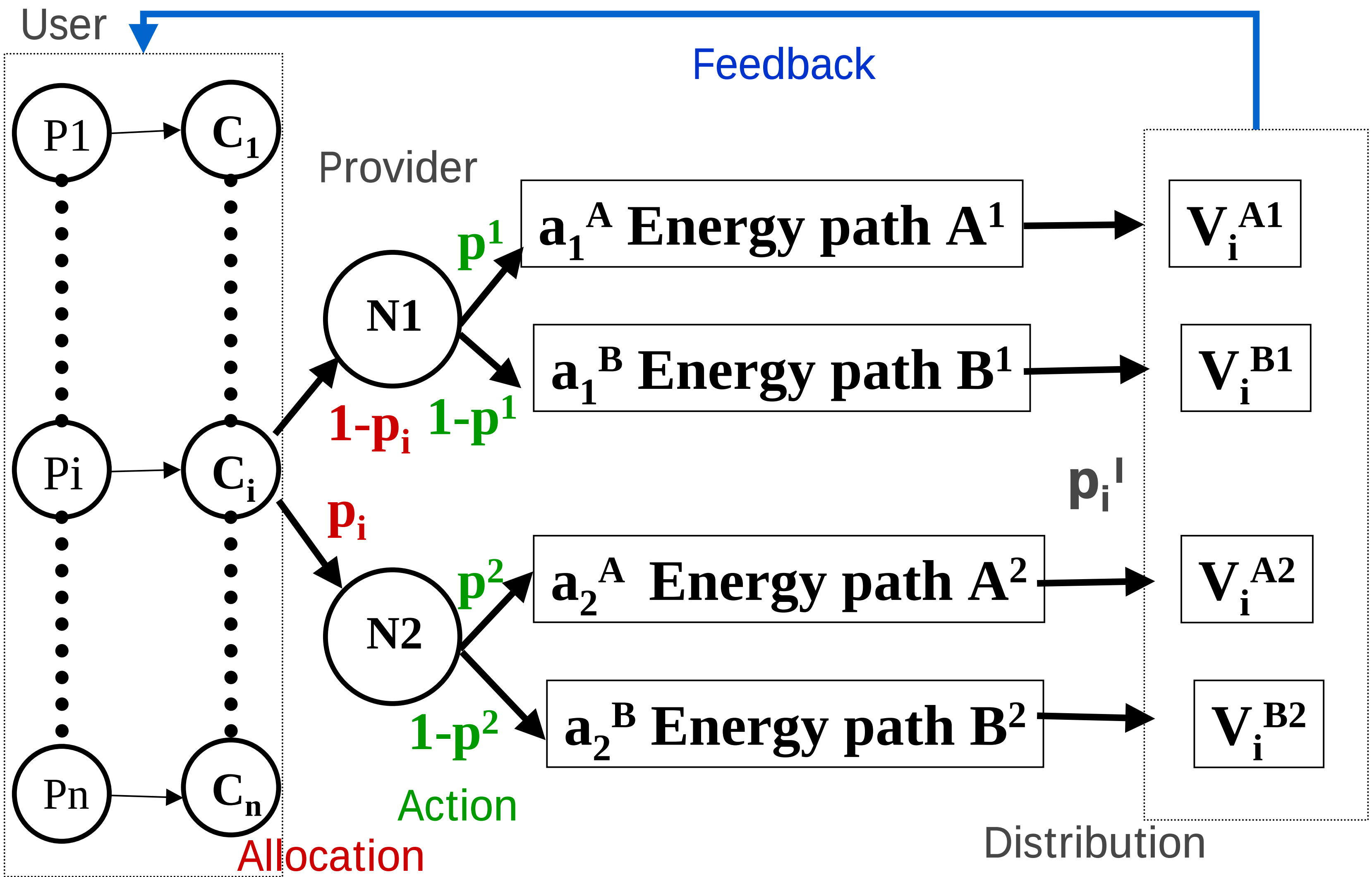




GDP Losses from Emission Reductions

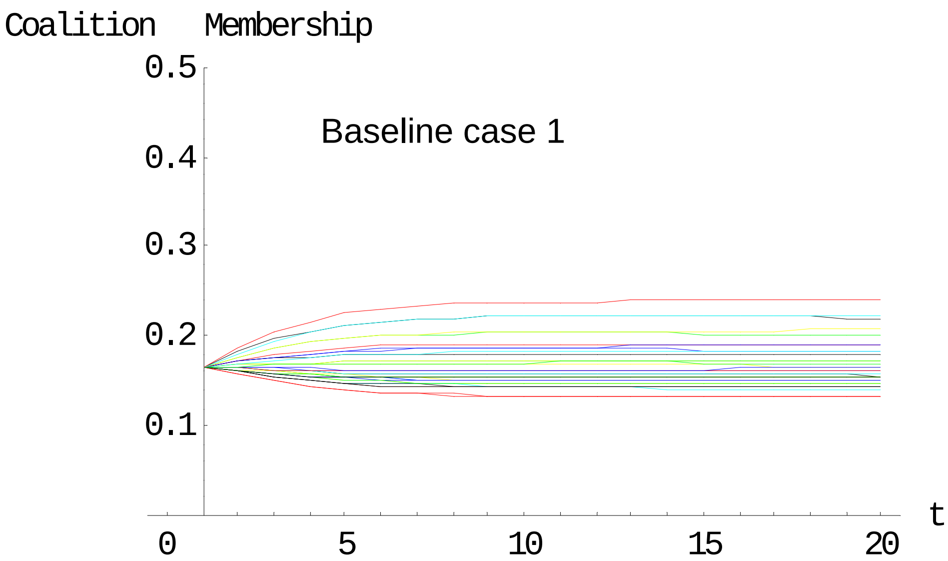


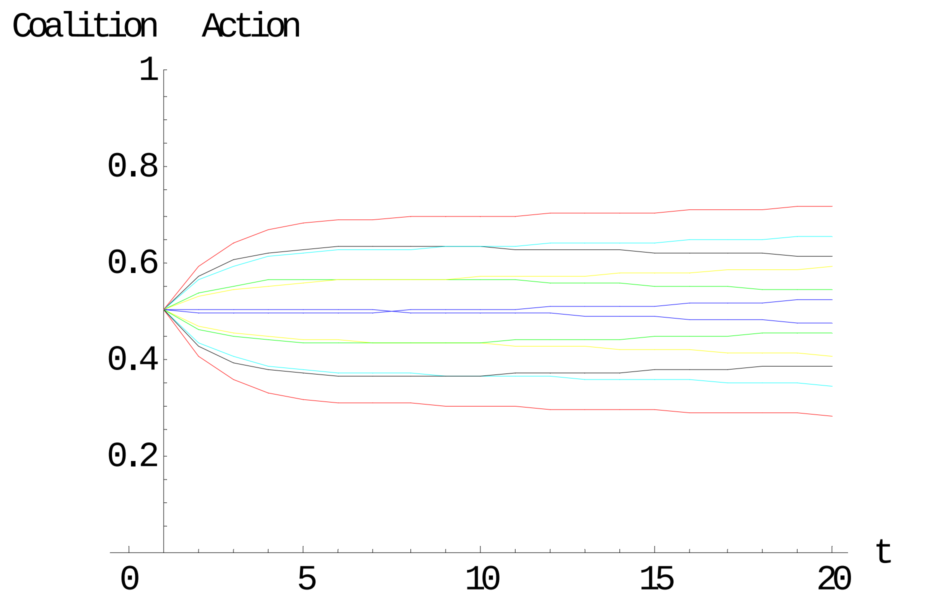
Coalition Formation in Energy Use

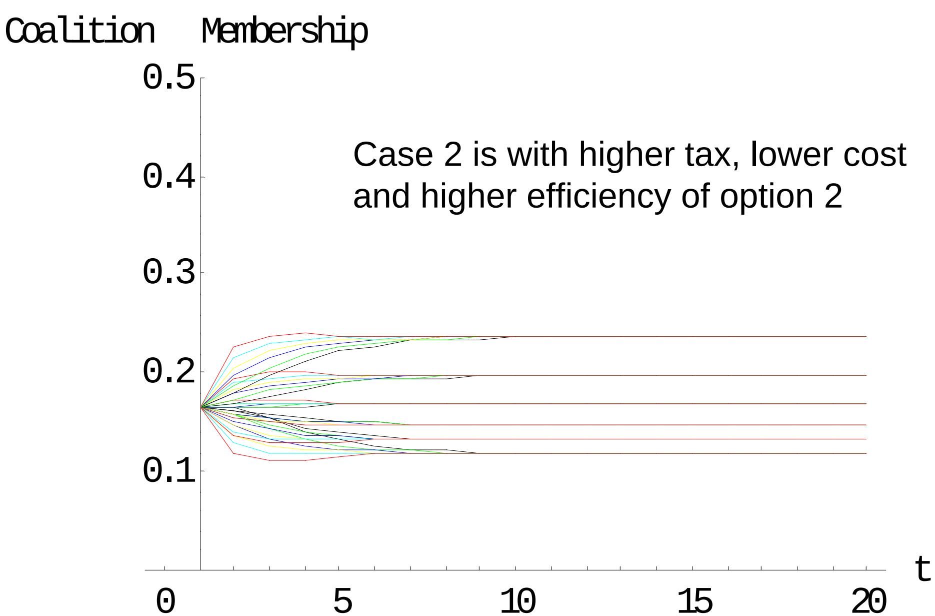


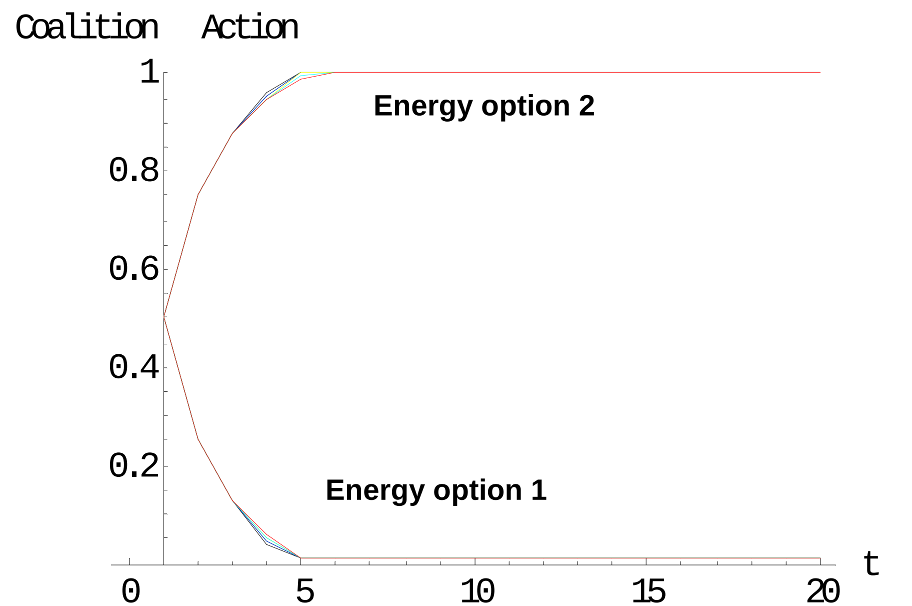
Coalitions in Energy Management

Simulation with 6 users and 6 providers of energy

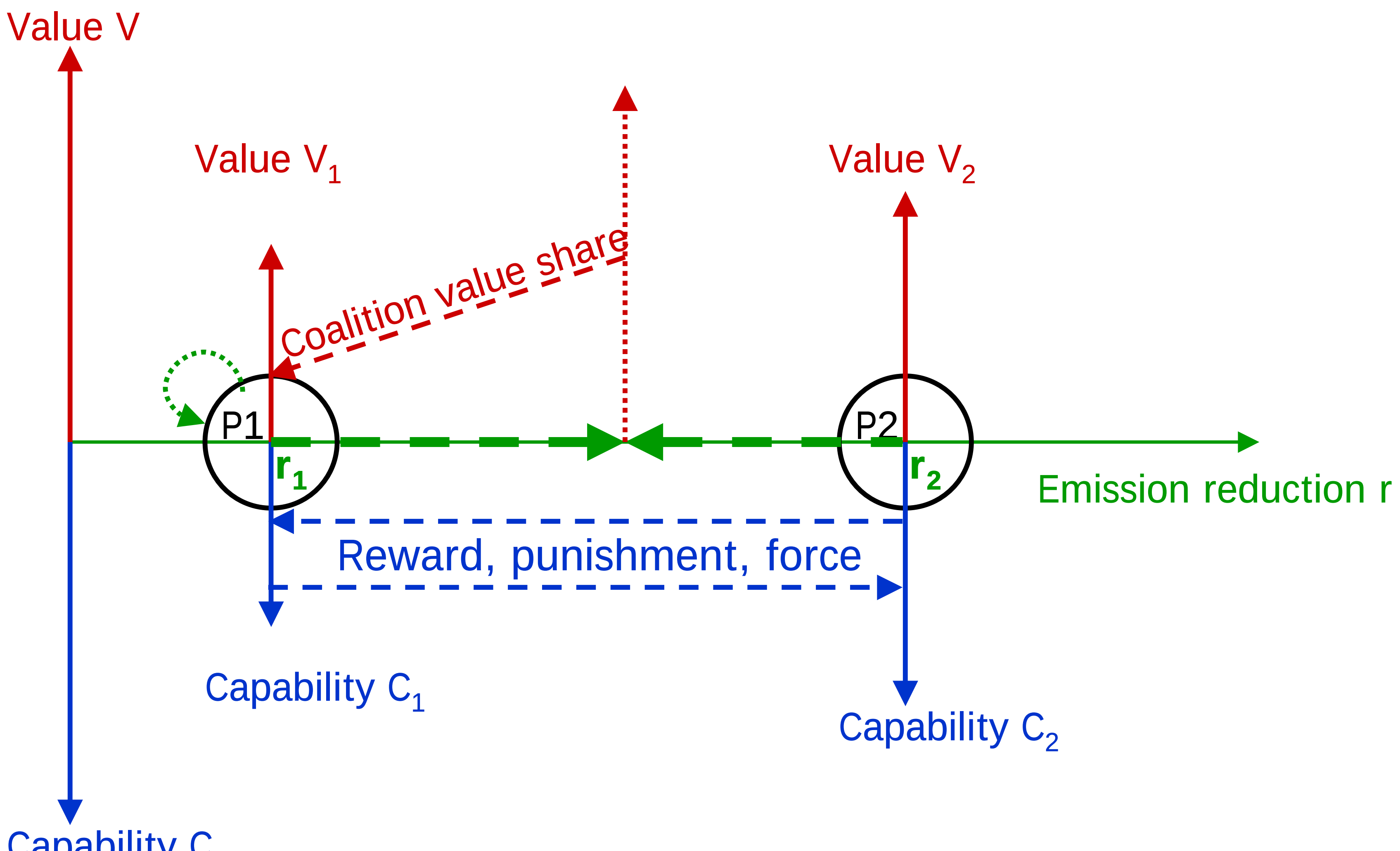




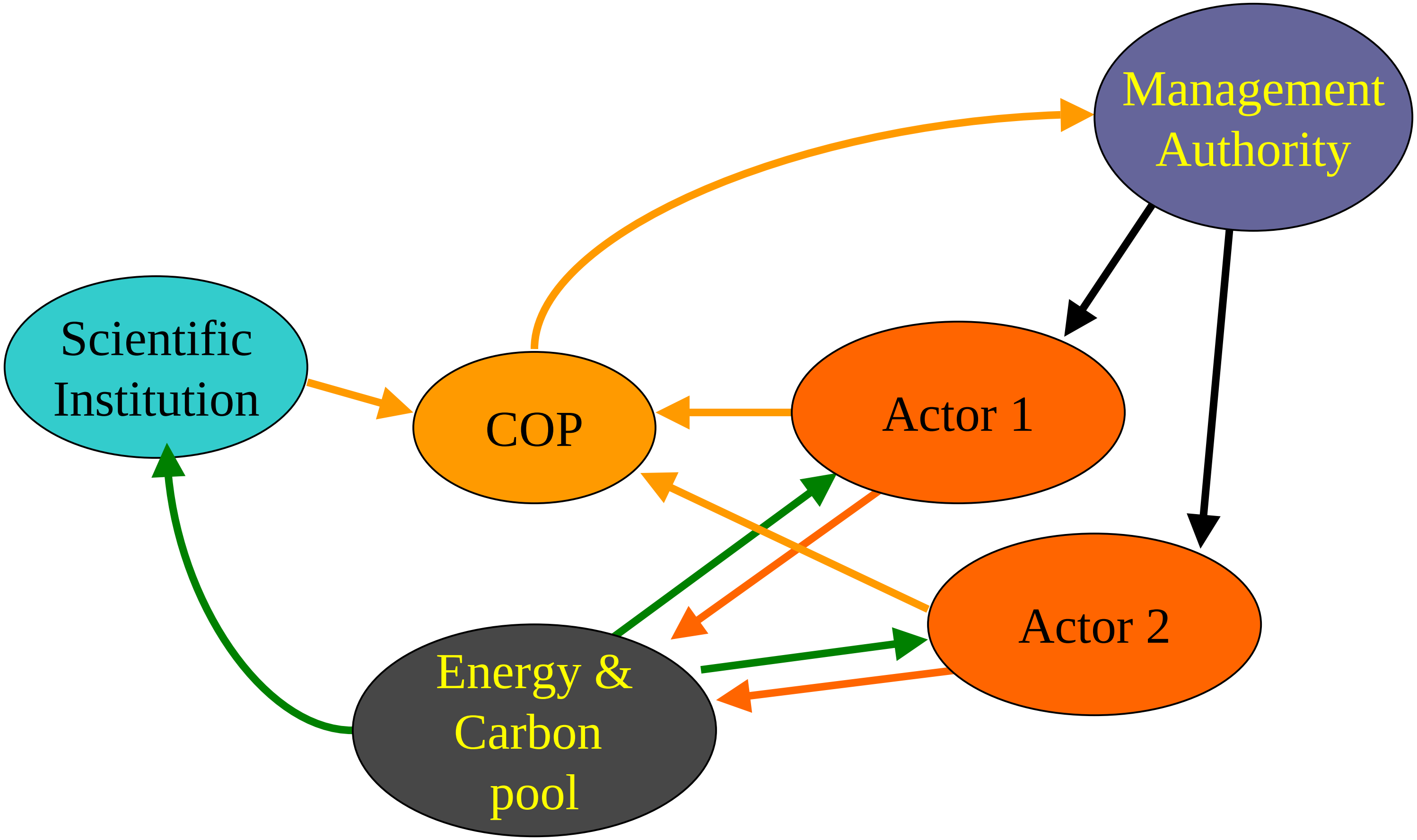




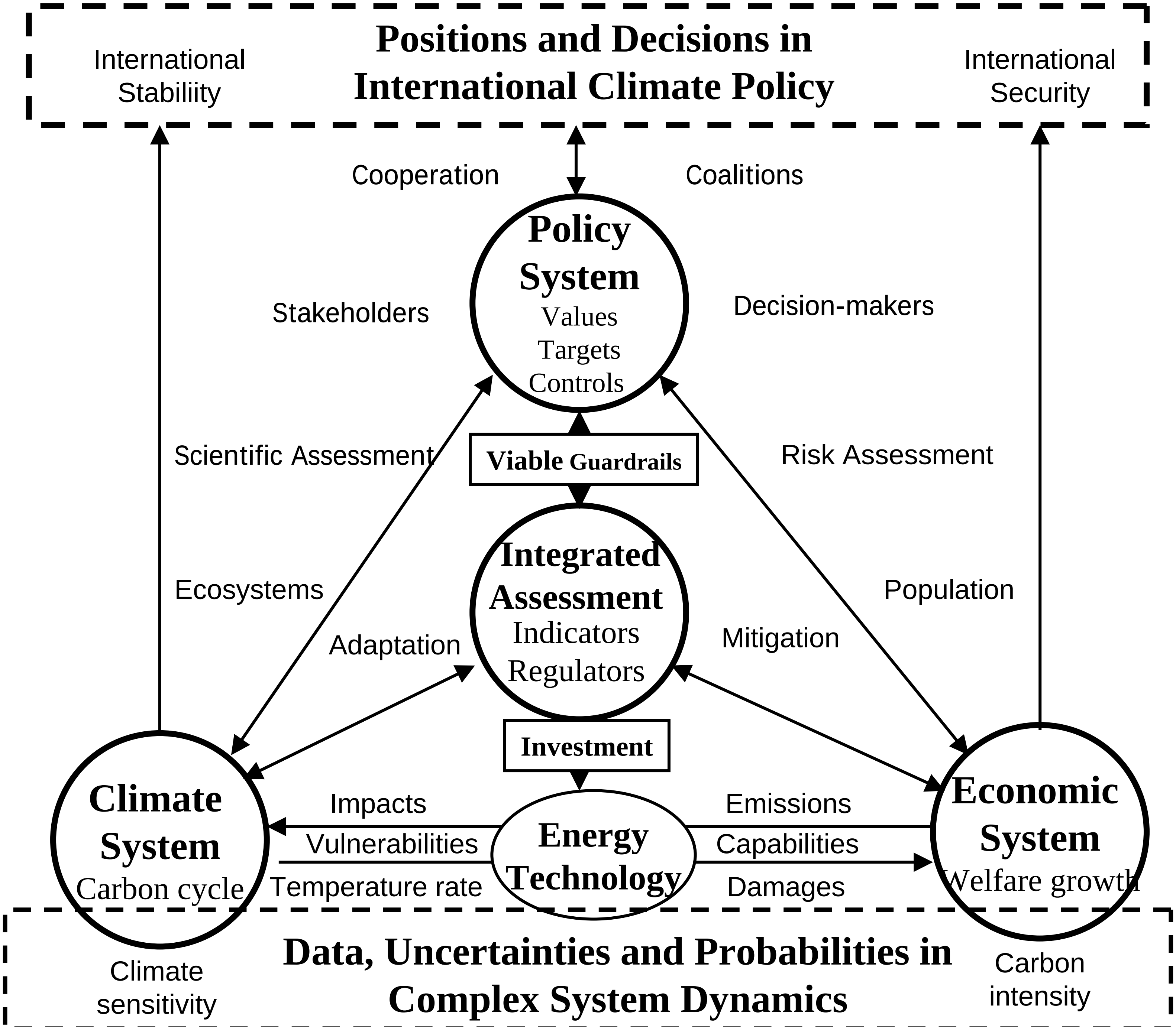
Factors Influencing Position Change



Cooperative Management of Energy and Climate Change



Modified from Eisenack, Scheffran, Kropp 2006



Positions and Decisions in International Climate Policy
International Stabiliity
International Security
Cooperation
Coalitions
Policy System
Values
Targets
Controls
Stakeholders
Decision-makers
Viable Guardrails
Scientific Assessment
Risk Assessment
Integrated Assessment
Indicators
Regulators
Ecosystems
Population
Adaptation
Mitigation
Investment
Climate System
Carbon cycle
Impacts
Vulnerabilities
Temperature rate
Energy Technology
Emissions
Capabilities
Damages
Economic System
Welfare growth
Data, Uncertainties and Probabilities in Complex System Dynamics
Climate sensitivity
Carbon intensity

Summary and Outlook

- Analyse and compare specific energy technologies and paths with regard to economic and environmental conditions, including climate change and risk assessment
- Use advanced methods and modeling tools within integrated assessment framework
- Provide data-based modeling tools for adaptive control and decision-making under uncertainty
- Develop and integrate climate, economy and decisionmaking tools into a probabilistic integrated assessment framework on emission reductions and climate change
- Involve multi-actor interaction in understanding the chance of realization of policy actions.