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Institut für Umweltentscheidungen
Institute for Environmental Decision

The Economics of Climate Change

Lecture 3: Optimal Emission Levels

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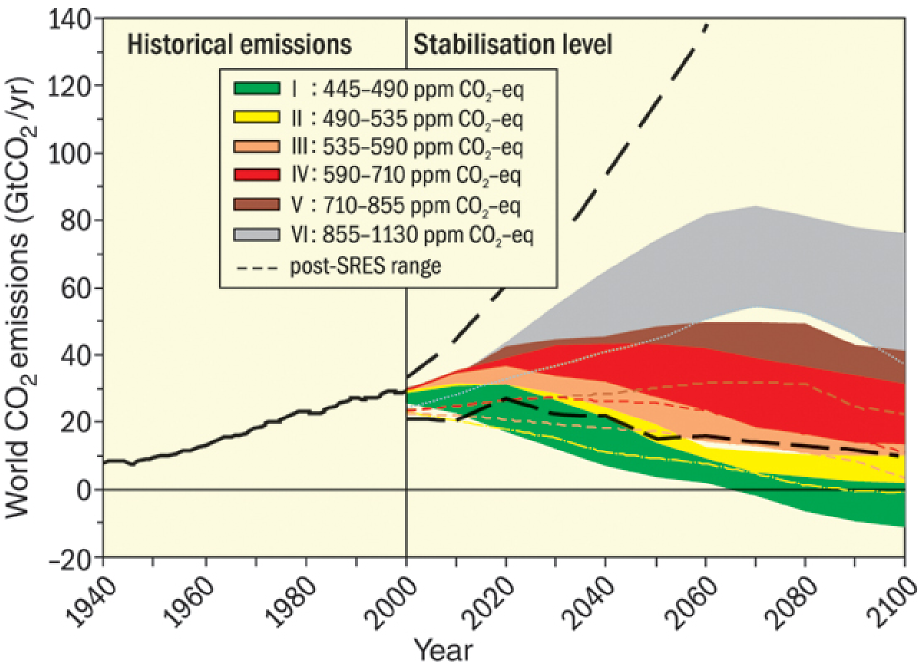
Previous lecture:

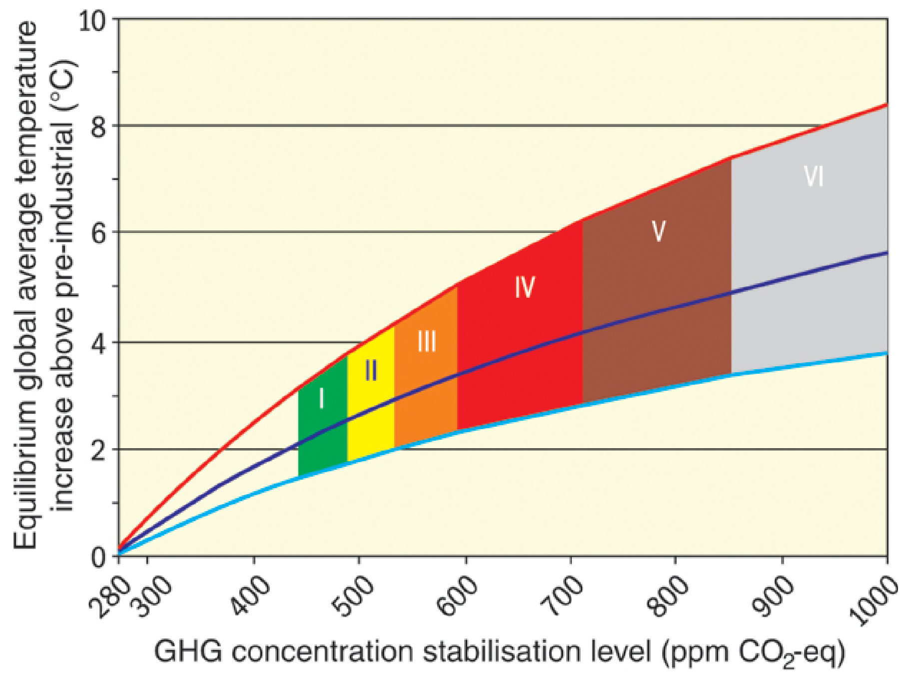
- Economic Efficiency and social optimality
- Efficiency and markets
- Pollution and market failure: public goods and externality
- Consequence: Inefficiencies from «over-pollution»

In this lecture:

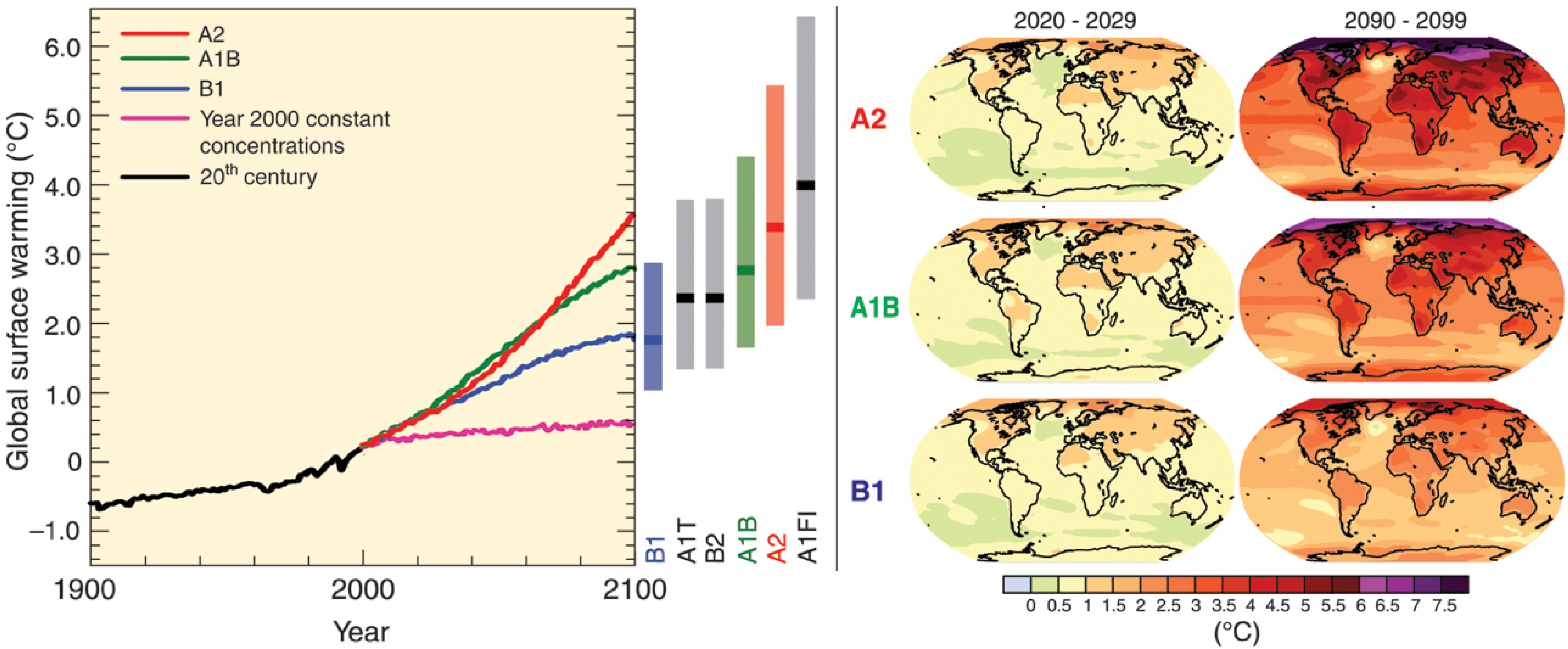
- We show the principles of deriving optimal emission levels in the context of climate change.

Scenarios and temperature increase





IPCC - Projections (scenario-based)



Emissions in Scenarios

- Kaya Identity (Kaya 1990):

$$CO_2 \text{ Emissions} = \text{Population} \cdot \underbrace{\frac{\text{GDP}}{\text{Population}}}_{\text{Wealth}} \cdot \underbrace{\frac{\text{Energy Consumption}}{\text{GDP}}}_{\text{Energy Intensity of Output}} \cdot \underbrace{\frac{\text{Emissions}}{\text{Energy Consumption}}}_{\substack{\text{Emission Intensity} \\ \text{of Energy Production}}}$$

- This identity is quite helpful when thinking about future emissions and points of intervention
- But: What about the stringency of climate policies (e.g. emission taxes) over time?

How much emitted GHGs should be allowed

- From lecture 1 we saw that a target of 550ppm has been chosen to control GHG, is this optimal? is this efficient?
- answer: it depends on your objectives!

From economist's point of view:

- Focus on optimality: Aim is to maximize welfare: efficient allocation of resources in economy
- Problem: policymakers do not know all relevant information.
- Solution: focus on efficient outcome by trying to maximize discounted net benefits over a time horizon

Damage from pollution

- GHG is a stock pollutant: damages to the economy depend on the stock of the pollutant (as opposed to the flow of the pollutant) Stock is the flow of the pollutant minus the decay of the pollutant in the atmosphere

Damages over time

- From lecture 2, the damage function shows the externality produced by GHGs, i.e. uncompensated costs borne by society due to the level of GHG...it is a public bad.
- The damage function encapsulates all damages to the world and produces a monetary value. Realistic?

Damage to society is given by the function:

$$D_t = D_t(A_t)$$

where t is the time subscript and A_t is the **stock of GHG** at time t

- Usually assumed that D’(·)>0 and D’’(·)>0

Pollution dynamics (continuous time)

- As we are discussing GHG, the rate at which the stock (A_t) changes depends on:

$$\dot{A}_t = M_t - \alpha A_t,$$

where $\dot{A}_t$ is the time derivative of A_t, i.e. $\frac{dA}{dt}$

– M_t is the current period emissions of GHGs which add to the stock

– αA_t is the decay of the stock of GHGs due to chemical processes

– $\alpha \in (0,1)$

– $\dot{A}_t > 0$: Stock is increasing

– $\dot{A}_t < 0$: Stock is decreasing

Benefit of pollution

- Assume that firms produced good with no pollution $\Rightarrow$ prohibitively expensive
- Now consider this constraint is relaxed, the cost of pollution abatement falls (and hence profits rise)
- So benefit of pollution is the profit obtained in being allowed to emit pollution.
- The net benefit function of GHGs is denoted by:
- $B_t = B_t\,(M_t)$
- where t is the time subscript and M_t is the **flow** of current GHGs with $B_t > 0$ and $B_t < 0$, as the per unit abatement costs will larger the greater the amount of pollution reduction.

Consumption discount rate

- (consumption) discount rate *r* show the preferences for consumption in future periods

- intertemporal welfare:

$$W = U_0 + \delta U_1 + \delta^2 U_2 + \ldots + \delta^T\ U_T$$

- this shows weighting of consumption U_t for each period t

$$\delta = \frac{1}{1+r}$$

- so for r > 0 the future "counts less" for same quantity today

- In continuous time this is most often presented as:

$$W = \int_{t=0}^{T} U_t \cdot e^{-rt}\ dt$$

The intertemporal optimization problem

- The objective of the policy (law) maker is to select a target level of Greenhouse gases in each period to maximise the discounted net benefits over some time horizon T:

$$\max_{M_t} \int_{t=0}^{T} \left[B(M_t) - D(A_t)\right] \cdot e^{-rt} \, dt,$$

such that

$$\dot{A}_t = M_t - \alpha A_t$$

$$A_0 = A(0) \geq 0$$

$$M_t \geq 0$$

where r is the social discount rate in the economy, which is usually assumed to be constant.

- To solve this we create a current-valued Hamiltonian:

$$H_t = B_t(M_t) - D_t(A_t) + \mu_t(M_t - \alpha A_t)$$

- First order conditions are:

$$\frac{\partial H_t}{\partial M_t} = 0 \Leftrightarrow \frac{\partial B_t}{\partial M_t} + \mu_t = 0$$

$$\dot{\mu} = \frac{\partial H_t}{\partial A_t} + r\mu_t = \frac{\partial D_t}{\partial A_t} + \alpha\mu_t + r\mu_t = 0$$

- Simplifying Assumption:

  $\frac{d\mu}{dt} = 0$, i.e. the future gains/losses from a marginal change in emissions are constant (constant shadow price).

- This yields:

$$\frac{\partial B_t}{\partial M_t} + \mu = 0$$

$$\frac{\partial D_t}{\partial A_t} + \alpha\mu + r\mu = 0$$

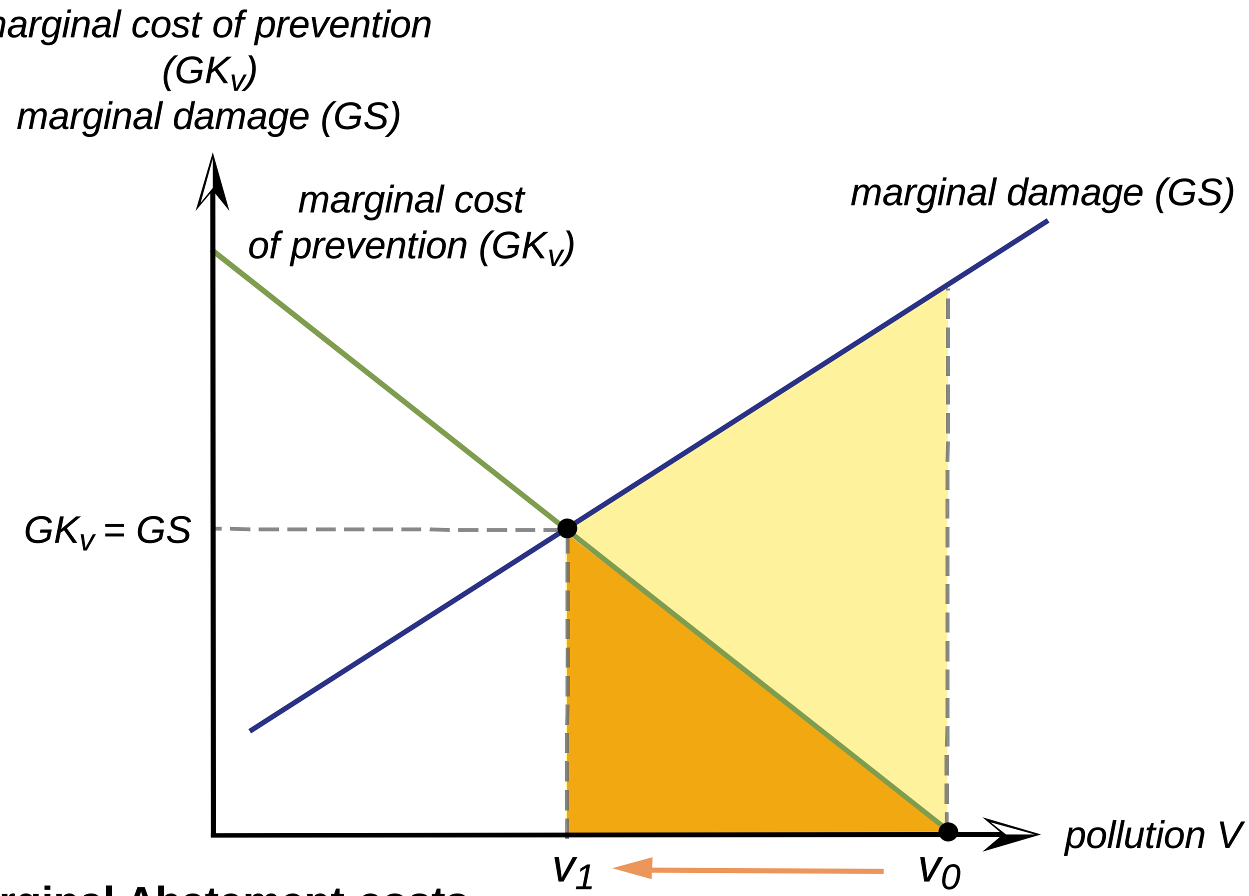
Substituting μ and taking into account that $\frac{\partial D_t}{\partial A_t} = \frac{\partial D_t}{\partial M_t}$ yields:

$$\frac{\partial B_t}{\partial M_t} = \frac{1}{r+\alpha} \cdot \frac{\partial D_t}{\partial M_t},$$

- Which determines the optimal level of emissions M_t^*

- In other words, greenhouse gas emissions should be set at the level where the present value of net marginal benefits equals the present value of damage from the marginal unit of pollution (while taking decay into account)
- In other words, this also corresponds to MAC = MD!
- Note the decay rate alters the level of optimal emissions $\Rightarrow$ different level of optimal emissions for all greenhouse gases

Optimal level when damages can be anticipated (Welfare maximization)



- Optimal Emission level V_1 is to be incentivized.
- This is achieved by putting a «price on carbon»
- Optimal carbon price p:

p = Marginal Damages = Marginal Abatement costs

Damages and Uncertainty

		Uncertainty in Valuation →		
Uncertainty in Predicting Climate Change ↓		Market	Non Market	(Socially Contingent)
	Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
	Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
	System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Source: Downing and Watkiss, 2003

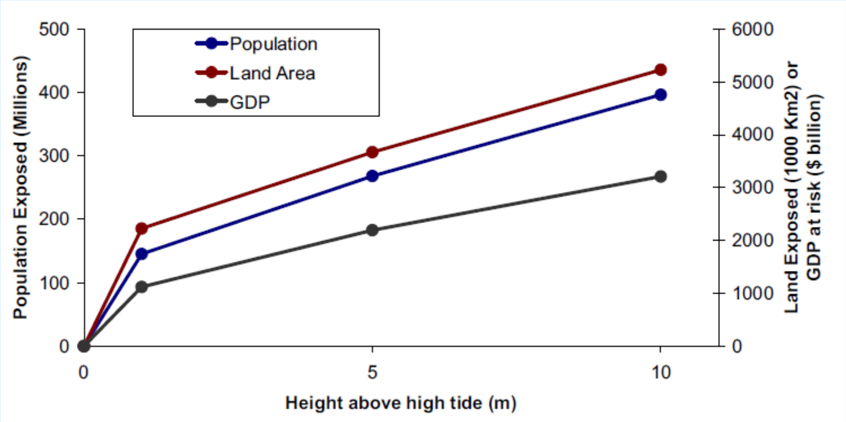
The problem of specifying the damage curve

Table 3.3 Potential temperature triggers for large-scale and abrupt changes in climate system

Phenomenon	Global Temperature Rise (above pre-industrial)	Relative Confidence*	References
Shifts in regional weather regimes (e.g. changes in monsoons or the El Niño)	Uncertain (although some changes are expected)	Medium	Hoskins (2003)
Onset of irreversible melting of Greenland	2 - 3°C	Medium	Lowe *et al.* (2006)
Substantial melting threatening the stability of the West Antarctic Ice Sheet	> 2 - 5°C	Low	Oppenheimer (2005)
Weakening of North Atlantic Thermohaline Circulation	Gradual weakening from present	High	Wood *et al.* (2006)
Complete collapse of North Atlantic Thermohaline Circulation	> 3 - 5°C	Low	O'Neill and Oppenheimer (2002)

Source: Adapted from Schneider and Lane (2006)

Figure 3.11 Global flood exposure from major sea level rise (based on present conditions)

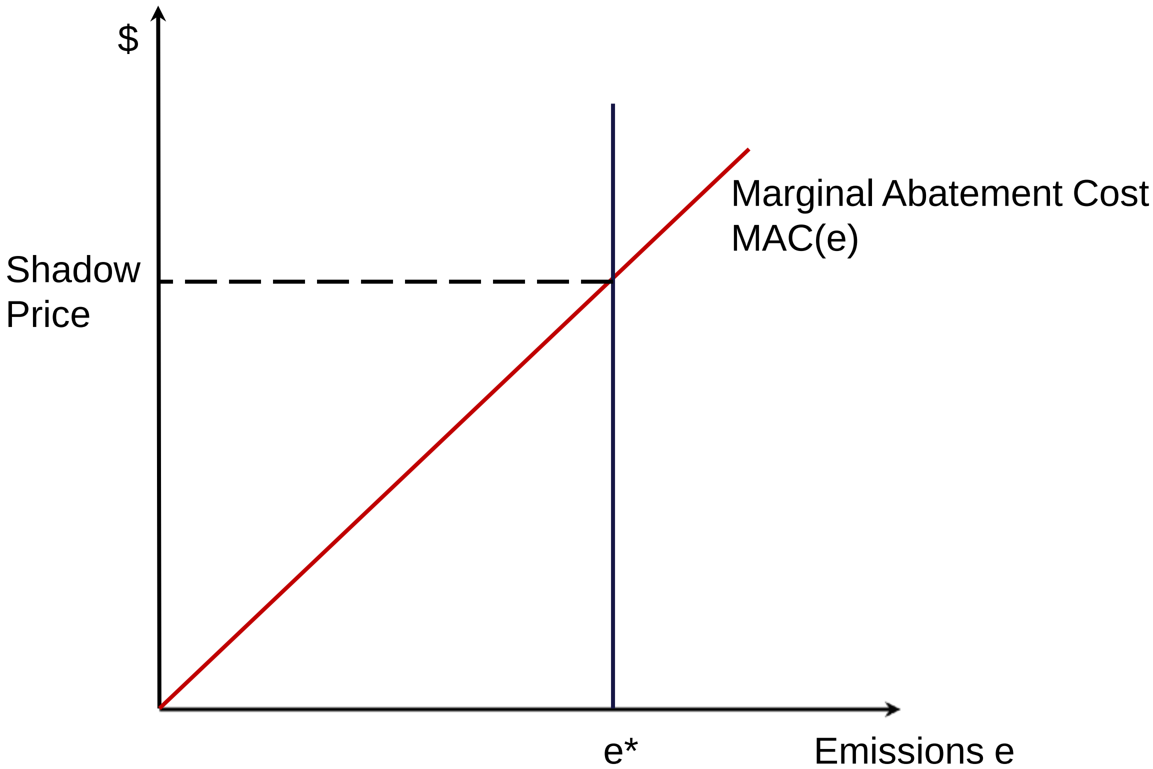


Source: Anthoff *et al.* (2006)

Minimizing Abatement costs under an environmental constraint

Environmental constraints:

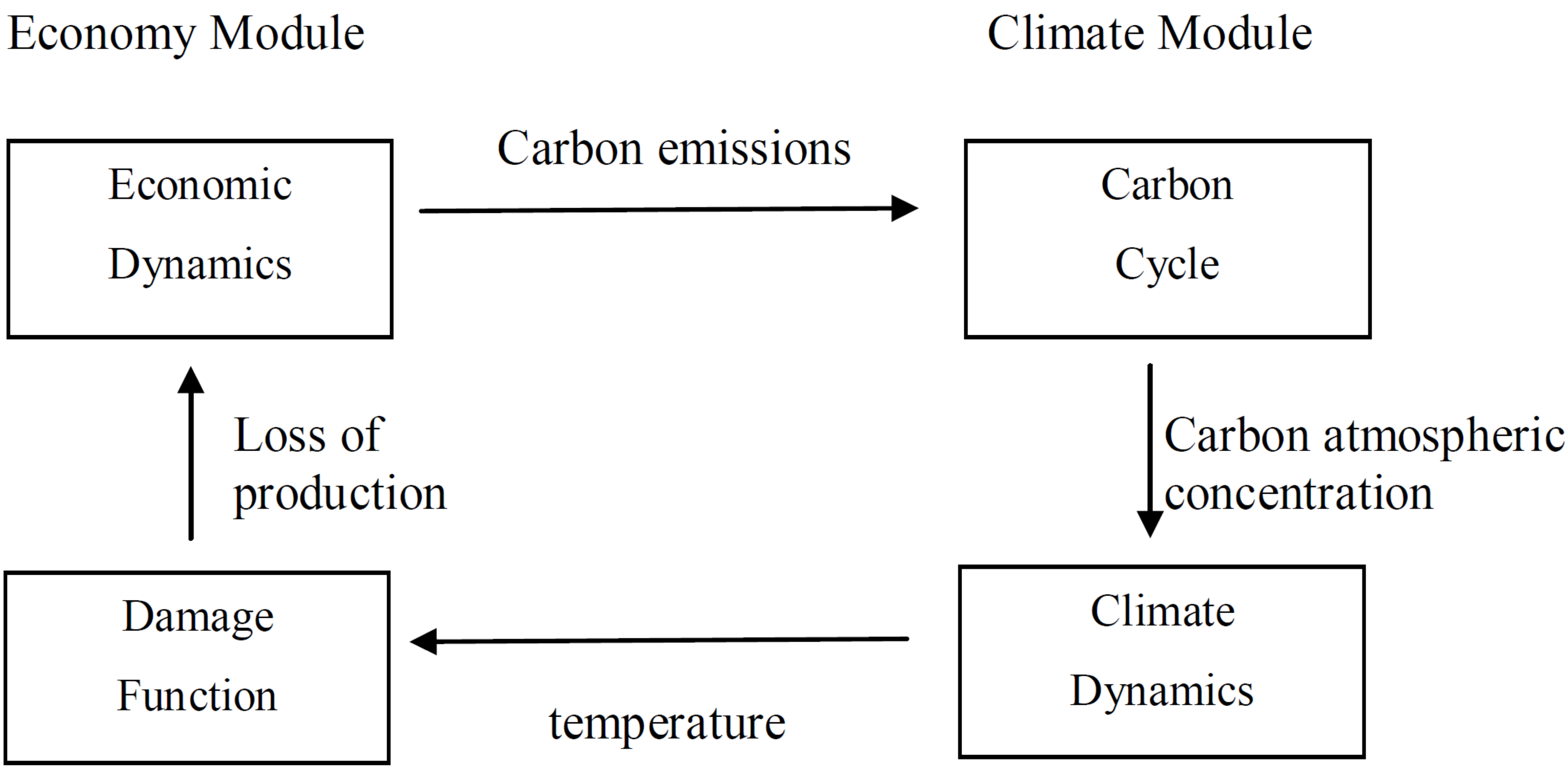
- Temperature not exceeding 2°C
- Concentration not exceeding 550 ppmv
- Constraints are usually probabilistic, e.g. target is met with x% probability



Integrated Assessment Models

- IAMs are combined climate and economic models which allow a joint modelling of natural and socio-economic processes
- Primary analytical tool for quantitative climate policy analysis
- Used to predict the impacts of GHG emissions and to evaluate the optimal abatement path (when, where and how much to abate)
- First climate-economy IAM developed by Nordhaus (1991)

Simplified structure of IAMs



Source: Arigoni Ortiz and Markandya (2009)

Strenghts of IAMs

- Consistent modelling of economy, climate and biosphere
- Consideration of feedbacks between the different domains
- Often global coverage, sometimes regionally disaggregated
- Long time scales

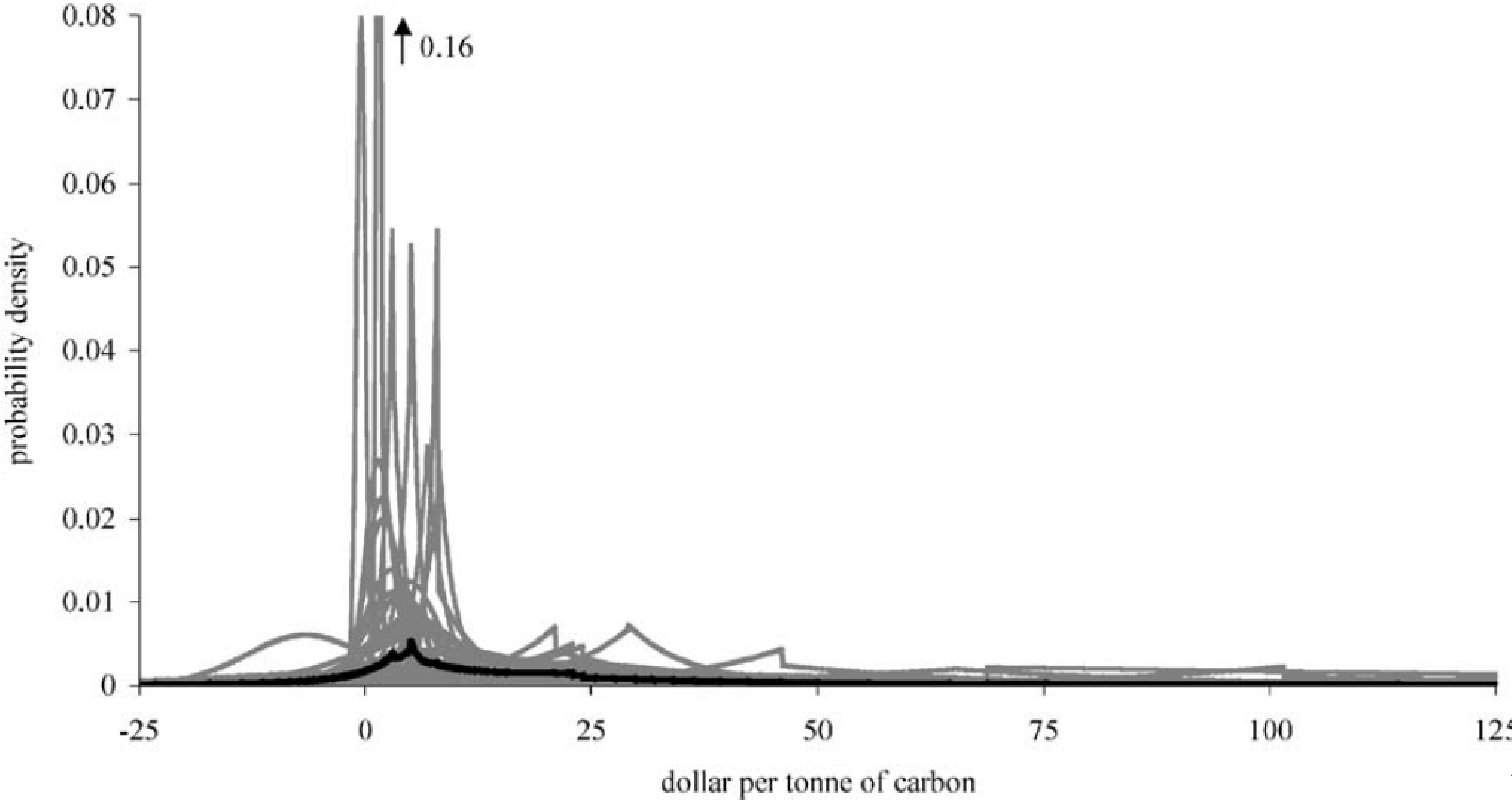
Weaknesses of IAMs

- Trade-off between level of accuracy within the sub-models and width of coverage
- High complexity, sometimes low transparency with respect to assumptions made → «black box»
- Requirement of high computer power to solve models
- Adequate uncertainty analysis often difficult

Differences in IAM results

Estimates for the social cost of carbon (SCC) diverge:

\$93/tC (mean), \$14/tC (median), \$350/tC (95 percentile) (Tol, 2005)



Source: Tol (2005)

Main drivers of differences in IAM results

1) Choice of model structure
2) Treatment of abatement costs and assumptions on technological change
3) Way of handling uncertainty in climate outcomes (9.10.)
4) Way of handling equity across time and space (9.10.)

1) Typical model structures of IAMs

a) Welfare maximization models

b) General equilibrium models

c) Partial equilibrium models

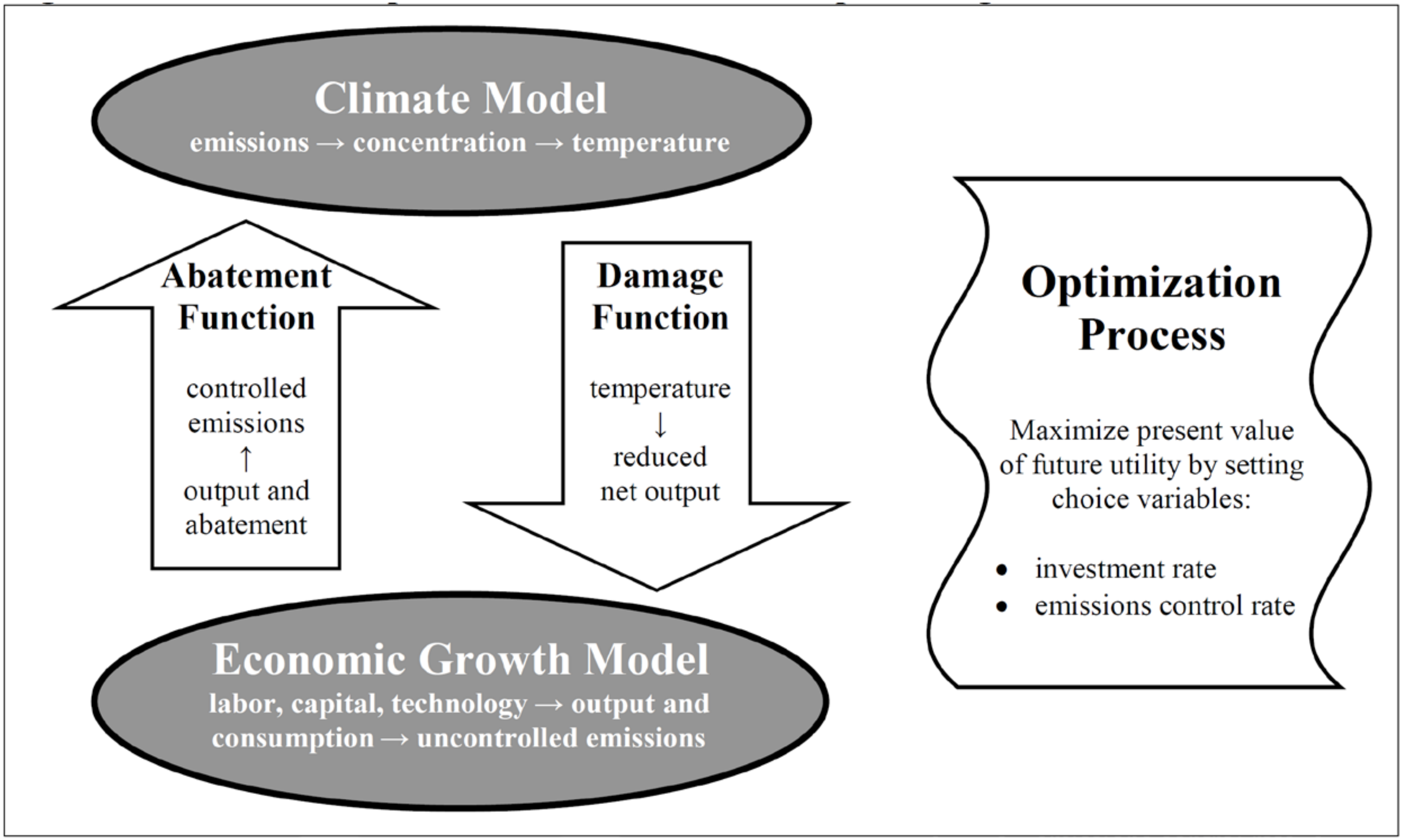
d) Simulation models

e) Cost minimization models

a) Welfare maximization models

- The economy is represented in a growth model
- The discounted present value of welfare is maximized across all time periods → Optimization over the amount of abatement in each period
- All time periods are solved simultaneously (perfect foresight)

Structure of welfare maximization model



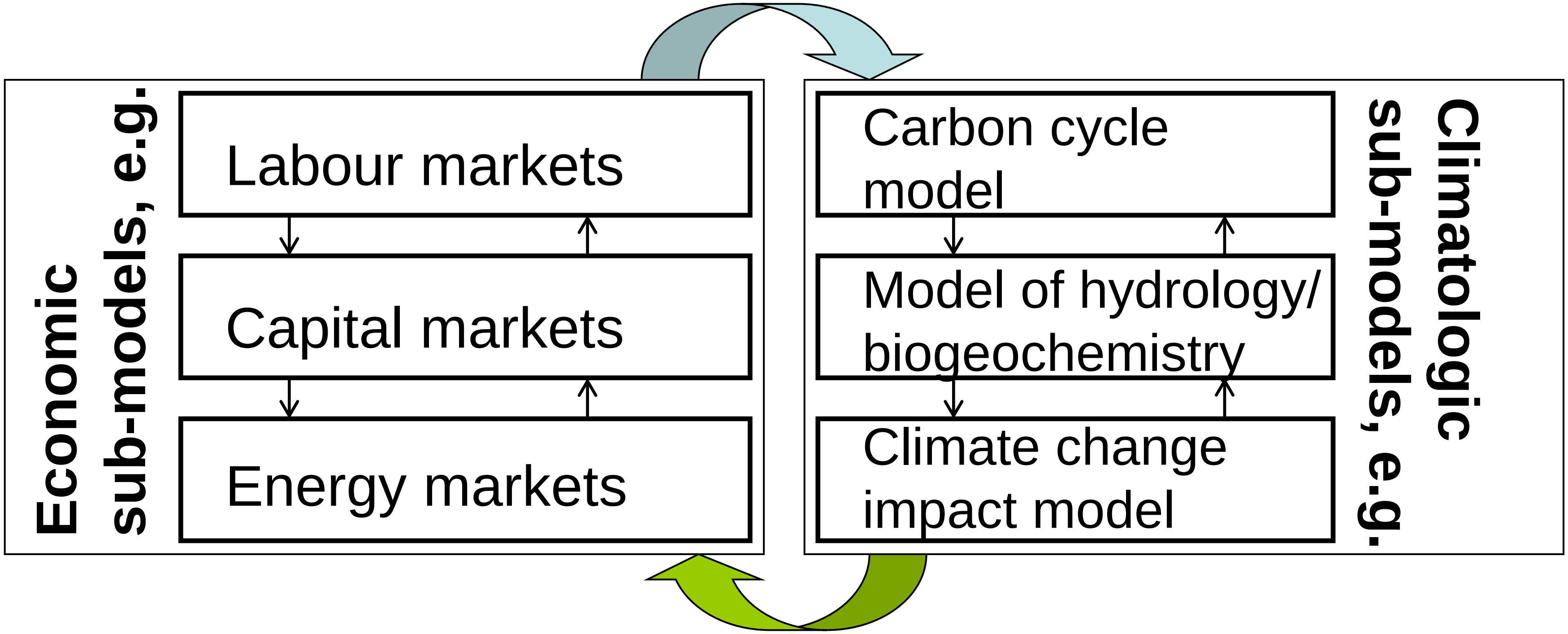
Source: Stanton et al., 2008

b) General equilibrium models

- Economy is represented in a set of linked economic sub-models (different sectors)
- Models are solved by finding a set of prices for which all markets are cleared
- «Recursive dynamics»: prices are set for each time period; results are used as inputs for next time period (no perfect foresight assumed)
- GE models are often very complex

Simplified structure of GEM

Information about GHG emissions from economic activity



Information about climate and temperature changes

c) Partial equilibrium models

- PE models correspond to reduced GE models, i.e. they use only a subset of the economic sectors
- Prices of economic sectors not represented in the model are taken as exogenously given (fixed)

d) Simulation models

- Based on predictions about future emissions and climate conditions
- No feedback between climate and economic models, i.e. climate and emission parameters are exogenous to the model (Scenarios)
- Estimation of the potential costs of different future emission paths

e) Cost minimization models

- In most cases, no feedback between climate and economic models → only emissions are represented
- Very detailed modelling of energy sector and different industries
- Identify the most cost effective solution to achieve a certain stabilization target

Overview of some recent IAMs

Model Category	Global	Regionally Disaggregated
Welfare Maximization	DICE-2008 ENTICE-BR DEMETER-1CCS *MIND*	RICE-2004 FEEM-RICE FUND MERGE CETA-M GRAPE AIM/Dynamic Global
General equilibrium	JAM IGEM	IGS/EPPA SMG WORLDSCAN ABARE-GTEM G-CUBED/MSG3 MS-MRT AIM IMACLIM-R WIAGEM
Partial Equilibrium		MiniCAM *GIM*
Simulation		PAGE-2002 ICAM-3 E3MG *GIM*
Cost MInimization	GET-LFL *MIND*	DNE21+ MESSAGE-MACRO

Note: Italics indicate that a model falls under more than one category

Source: Stanton et al., 2008

2) Treatment of abatement costs and assumptions on technological change

- Characterization of technologies by decreasing or increasing returns to scale?
- Level of detail in technology sub-models: How many regions, industries, fuels, abatement technologies and end uses are included?
- Does the model include macroeconomic feedback from investment in abatement technology?
- Is technological change exogenous or endogenous?

Decreasing vs. increasing returns to scale

- Many IAMs characterize technologies with decreasing returns to scale
- Decreasing returns to scale are usually used for convenience (to avoid path dependence and multiple equilibria)
- Increasing returns to scale is more realistic, esp. when representing knowledge-based technologies

Accounting for macroeconomic feedback

- In many IAMs, abatement costs are considered as loss of income
- More realistic approach:
  - Account for job and income generating effects of abatement
  - Consider abatement costs as additions to capital rather than subtractions from income

Endogeneity of technological change

- In many IAMs, technological change is exogenous → technological learning curves are taken as given
- More realistic approach: make technological change dependent on investment and R&D efforts → model technological change as an outcome of economic activity
- In tendency, models including endogenous technological change provide lower estimates of abatement costs (Edenhofer et al., 2006; Barker et al., 2006)

Conclusion

- Even without taking more uncertain effects into account, theoretically optimal carbon prices seem to suggest that quite stringent climate policy should be implemented.
- When also considering non-linear effects and the fact that such policies also trigger innovation, the need for global climate policy seems to be more and more undisputable.