Towards a Global Contract on Climate Change

Santa Fe, 24th July 2009

Summer School on Global Sustainability
Assessing the Solution Space

- Population
- Per Capita Production
- Energy Intensity
- Carbon Intensity
- CO₂ Capture at Plant (CCS)
- Life-Style Change Technologies
- Non-Fossil Energy
- CO₂ Released
- CO₂(A)/CO₂
- Population
- GDP / Pop
- E / GDP
- CO₂ / E
- CO₂ Released
- CO₂(A)/CO₂
- Carbon cycle
- Ocean Acidification
- Impacts
- Agricultural Practices etc.
- CO₂ Emissions
- Other GHG Emissions
- Radiative Forcing
- Climate Change
- 2º/ 3º/ 4º Policies
- Carbon Management
- Adaptation
- Radiation Management
- Radiation Management
What about Tippint Points?

![Diagram showing Marginal Abatement Costs and Marginal Damages with a point E']
What about Technological Change?

[Diagram showing Marginal Abatement Costs and Marginal Damages intersecting at E' for optimal emissions and E'' for tolerable emissions.]
Multiple Equilibria and Non-Convex Optimization
Discounting and Technological Change

Based on IEA Data (1971-2005) and REMIND results for 450ppm-eq (ADAM); Graphic by Steckel/Knopf
The Neglected Supply Side

Edenhofer, Kalkuhl (2009)
Architecture of a Global Contract

Global Contract

Effectiveness – Efficiency – Equity

Global Carbon Market
Technology
Reducing Deforestation
Adaptation
Architecture of a Global Contract

Global Contract

Effectiveness – Efficiency – Equity

Global Carbon Market
Technology
Reducing Deforestation
Adaptation
Towards a Global Carbon Market

1. The fundamental problem
2. Burden sharing
3. Delayed participation
4. Linking
5. EU ETS
The Hotelling Model
The “Green Paradox“ (Model)

Optimal resource extraction under climate change:

\[
\max_{R_t} \int_0^\infty f(K_t, R_t, S_t) - g(S_t) e^{-rt} dt
\]

- Usual convexity conditions: \( f_X > 0, f_{XX} < 0, g_S < 0 \)

- \( f_S \) – marginal climate productivity depends on cumulative resource extraction (equals marginal damages); climate productivity additively separable

- Initial stock \( S_0 \) depletes with extraction: \( \dot{S}_t = -R_t \); \( S_t \geq 0 \)

- Socially optimal Hotelling rule:

\[
r = \frac{\dot{f}_R + f_S}{f_R - g(S)}
\]
**Lessons from the “Green Paradox“**

**Conventional Pigouvian tax** cannot solve the incentive problem for stock-pollutant ➔ inefficient

\[
\max_{R_i} \int_{0}^{\infty} (p_t - g^i(S_t^i) - \tau_t) R^i_t e^{-\rho t} dt
\]

- \( p \) – resource price
- \( R \) – fossil resources
- \( S \) – resource stock
- \( g \) – extraction costs
- \( \tau \) – unit tax

**i-th resource owner’s problem:**

**Pigouvian tax:**

\[
\tau_t = \tau(S_t) = \frac{f_s}{\rho}
\]

**How do resource owners anticipate the change of \( \tau \) ?**

**Pigouvian tax changes with aggregated, cumulative extraction!**

But resource owners do only see a weak (or even no) relation between individual extraction and aggregated extraction.
Lessons from the “Green Paradox“

Hotelling rule for the $i$-th resource owner with $n$ identical resource owners and conventional Pigouvian tax:

$$
\begin{align*}
\dot{p} + f_S + \frac{f_{SS}}{n-1} \frac{n-1}{n} R &= 0 \\
r &= \frac{f_S}{p - g(S)}
\end{align*}
$$

Suboptimal extraction path ("Green Paradox")

- Acceleration of extraction due to $f_{SS} < 0$
- Tax is inefficient and ineffective
- Resource sector suffers from internal public good problem with respect to $\tau(S)$

Suboptimal extraction path ("Green Paradox")

<table>
<thead>
<tr>
<th>$n=1$</th>
<th>Correct anticipation of damages</th>
<th>$r = \frac{\dot{p} + f_s}{p - g}$</th>
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<tbody>
<tr>
<td></td>
<td>Tax as feedback instrument</td>
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<table>
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<tr>
<th>$n=\infty$</th>
<th>Only time-path is anticipated</th>
<th>$r = \frac{\dot{p} + f_s + \frac{f_{SS}}{r}}{p - g(S)}$</th>
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<td></td>
<td>Tax as open-loop instrument</td>
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</table>
Lessons from the “Green Paradox“

Central control of extraction and complete absorption of resource rent: Information and implementation problems

\[ \max_{R_t} \int_0^\infty (p_t(1-\xi_t) - g^i(S_t^i) - \tau_t)R_t^i e^{-rt} dt \]

i-th resource owner’s problem:

Tax regime:

\[ \xi_t = 1, \quad \tau_t^i = g^i(S_t^i) \]

• 100% ad-valorem tax on resource price
• Tax refund for extraction costs
• No Hotelling dynamics in the resource sector
• Regulator has to decide in detail which resources when to extract (what are incentives for resource owners?)
• Information and implementation problems

Conventional Pigouvian tax
Central control of extraction
Dynamic (non-linear) Pigouvian tax
Decreasing cash flow tax or subsidies on non-extraction
Capital income tax
Emissions trading scheme
**Dynamic (non-linear) Pigouvian tax** is optimal, but difficult to implement

\[ \max_{R_t^i} \int_0^\infty (p_t - g^i(S_t^i) - \tau(S_t^i))R_t^i e^{-rt} dt \]

*i*-th resource owner’s problem:

Pigouvian tax for *i*-th resource owners:

\[ \tau(S_t^i) = \frac{f_s(nS_t^i)}{r} \]

- Tax changes with individual cumulative extraction
- Resource owners have to anticipate dynamic tax rule
- How to design tax for resource owners with heterogeneous extraction costs?
- How to determine individual share of aggregate stock damage (for infinite time horizon)?
Decreasing cash flow tax or subsidies on non-extraction: Credibility and commitment problems

\[
\max_{R_t} \int_0^\infty (p_t - g(S_t))(1 - \theta_t)R_t e^{-rt} dt
\]

Optimal cash flow tax:

\[
\dot{\theta}_t = \frac{-f_s^*}{p^* - g(S^*)} (1 - \theta_t) < 0
\]

- Decreasing tax \((f_s < 0, \theta < 1)\)
- Regulator has to know optimal trajectories \(p^*, S^*, f_s^*\)
- Regulator has to commit to tax path credibly for the entire (infinite) time horizon
- Regulator has to determine \(\theta_0\) (\(\theta\) will turn into a subsidy if \(\theta_0\) is choosen to small)
- Same problems for time-path altering unit or ad-valorem taxes or stock subsidies
Lessons from the “Green Paradox“

Capital income tax: Limited effectivity and distortions on capital markets.

\[ \max_{v_t} \int_0^\infty (p_t - g(S_t))R_te^{-r(1-v_t)t} \, dt \]

Optimal capital tax (Sinn 2008):

\[ v_t = \frac{f_S}{r(p - g(S))} \]

- High capital taxes flatten extraction path
- Distortions on capital markets (welfare losses)
- Capital tax might not work for ambitious mitigation target or backstops (zero extraction in the long run)
- International harmonization of existing capital taxes and closing down tax havens help to slow down extraction
Lessons from the “Green Paradox“

Conventional Pigouvian tax cannot solve the incentive problem for stock-pollutant ➔ inefficient

Control of extraction and complete absorption of resource rent ➔ information and implementation problems

Dynamic (non-linear) Pigouvian tax is optimal but difficult to implement

Decreasing cash flow tax or subsidies on non-extraction: Credibility, commitment and distribution problems

Capital income tax: Limited effectivity, vulnerable to other distortions on capital markets

➔ Internalizing damages might not be feasible !

➔ “Decentralized“ extraction-deposition problem of carbon stocks might not exist !

➔ Emissions trading scheme – an alternative ?
Lessons from the “Green Paradox“

Emissions trading scheme (ETS):

- Determines aggregated extraction path
- But leaves flexibility to resource owners:
  - What-Flexibility: coal, oil, gas, conventional/unconventional
  - When-Flexibility: if intertemporal flexibility is implemented

→ How to determine caps?
→ How to organize intertemporal permit trade?
→ What happens to the resource rents?

... to be explored

Conventional Pigouvian tax
Central control of extraction
Dynamic (non-linear) Pigouvian tax
Decreasing cash flow tax or subsidies on non-extraction
Capital income tax
Emissions trading scheme
Carbon Stocks – In Ground and Atmosphere

2000

Gas

Oil

Coal

Biomass + CCS

Gigatons Carbon

in the ground

in the atmosphere

0

1013

192

224

102

192

227

737

278

559

11163

240

reserves

cumulative historical consumption (1751-2004)
coal+CCS (zero-emissions; 400ppm-eq scenario)
biomass+CCS (negative emissions; 400ppm-eq scenario)
resources
estimated consumption (400ppm-eq scenario)
estimated additional consumption (BAU scenario)

Source: Edenhofer, Kalkuhl (2009)
Emissions Trading with Carbon Budget

Resource sector:

\[
\max_{R_t} \int_0^T (p_t - g(S_t))R_te^{-rt} dt
\]

s.t. \[\dot{S}_t = -R_t\]

\[\text{f.o.c.}\]
\[p_t = \lambda_t - g(S_t)\]

\[\dot{\lambda}_t = r\lambda_t + g_S(S_t)R_t\]

\[\text{transv. c.}\]
\[S_T\lambda_T = 0\]

Permit market:

\[
\max_{R_t} \int_0^T a_tR_te^{-rt} dt
\]

s.t. \[\dot{A}_t = -R_t\]

\[\text{f.o.c.}\]
\[a_t = \mu_t\]

\[\dot{\mu}_t = r\mu_t\]

\[\text{transv. c.}\]
\[A_T\mu_T = 0\]

As the permit stock is scarce, i.e. \(A_0 < S_0\), the entire permit stock is used \((A_T = 0)\) while the resource stock is not exhausted completely \((S_T > 0)\).

Due to the transversality condition in the resource sector, \(\lambda_T = 0\), i.e. there is no resource scarcity rent in the final period.

Resource extraction is dominated by the permit market.
Emissions Trading with Carbon Budget

Resource sector:
(resource rent)

\[
\lambda_t = -\int_t^T g_s(S_t) R_t e^{r(t-s)} ds
\]

- Zero extraction rent for constant extraction costs
- Policy reduces \(-g_s(S_t)\) and \(R_t\) and thus the extraction rent
- Pure scarcity rent is removed by policy as \(\lambda_t = 0\)

\(\rightarrow\) Small extraction rent for resource owners

Permit market:
(permit rent)

\[
\mu_t = a_t = a_0 e^{rt}
\]

- Pure scarcity (Hotelling) price \(a_t\) for permits from the exhaustible stock
- Calculation of \(a_0\) requires the assessment of optimal demand, extraction costs and extraction rent \(\lambda_t\)

\(\rightarrow\) Large scarcity rent for permit owners / regulator
Emission Trading within a Cost-Benefit Framework

• Full intertemporal flexibility (i.e. free banking and borrowing) leads to Hotelling path for the permit price $a_t$:
  \[ a_t = a_0 e^{rt} \]

• The optimal carbon price path $p_t$, however, has to consider damage dynamics:
  \[ r = \frac{\dot{p}_t + f_s}{p_t - g(S_t)} \]

• Intertemporal exchange rate integrates stock-damage into intertemporal arbitrage for permit trade:
  \[ \sigma_t = \frac{f_s^*}{\int_{t}^{T} f_s^* e^{r(t-s)} ds + \frac{f_s^*(T)}{r} e^{r(T-t)}} \]

• Initial permit stock:
  \[ b_0 = S_0 - \frac{\int_{0}^{T} S_t^* f_s^* e^{r(t-s)} ds + \frac{f_s^*(T)}{r} e^{r(T-t)} S_T}{\int_{0}^{T} f_s^* e^{r(t-s)} ds + \frac{f_s^*(T)}{r} e^{r(T-t)}} \]

• Permit bank:
  \[ \dot{b}_t = -R_t + \sigma_t b_t \]
Intertemporal Exchange Rate

Problems with exchange rates:

• Daunting informational requirements for the regulator
  – Optimal extraction / damage path has to be known

• The ex-post cumulative permit quantity is determined endogenously by market’s banking and borrowing decisions
  – Suboptimal arbitrage destabilizes the mitigation target

➔ Difficult to achieve optimal timing with intertemporal flexibility for markets

➔ Find pragmatic solutions
Why We Could Need a Central Carbon Bank

Issuing of permits in accordance with the remaining atmospheric deposit:

- Dividing the global budget into national budgets by international negotiations
- International and intersectoral permit trade for a cost-effective achieving of the budget
- National carbon banks guarantee long-term credibility of the budget

Manage timing:

- National carbon banks could set the time path directly
- National carbon banks could set intertemporal exchange rates and give intertemporal flexibility to the market

Resource extraction:

- > 11,000 GtC in the ground

Remaining atmospheric deposit:

- 330 GtC within 21st century
Budget Approach and A Simple Allocation Rule

\[ C_{nat} \equiv \int_{T_1}^{T_2} E_{nat}(t) \, dt = C_{glob}(p) \frac{M_{nat}(T_M)}{M_{glob}(T_M)} \]

national CO₂ budget = national emissions between \( T_1 \) and \( T_2 \) = CO₂ budget * share of population \( M \) in base year \( T_M \)

4 Parameters for multi-lateral negotiations:

• \( T_1 \): starting point, e.g. 1850 or 1990 or 2000
• \( T_2 \): end of negotiation period, e.g. 2050 or 2100
• \( p \): probability for keeping the 2°C target
• \( T_M \): e.g. 2010 to avoid „population policy“ by climate policy

WBGU 2009
„World Formula“

\[ C_{nat} \equiv \int_{T_1}^{T_2} E_{nat}(t) \, dt = C_{glob}(p) \frac{M_{nat}(T_M)}{M_{glob}(T_M)} \]

national \( \text{CO}_2 \) budget = national emissions between \( T_1 \) and \( T_2 \) = \( \text{CO}_2 \) budget * share of population \( M \) in base year \( T_M \)

Possible Parameters (e.g. in the WBGU approach)

- \( T_1: 2010 \)
- \( T_2: 2050 \)
- \( p: 66\% \)
- \( T_M: 2010 \)

WBGU 2009
Regional Mitigation Costs with Budget Approach

Regional budgets according to per capita allocation

Budget distributed according to mean per capita 2005-2050

- **Parameters here**
  - $T_1$: 2005
  - $T_2$: 2050 or 2100
  - $p$: 75%
  - $T_M$: mean 2005-2050

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How to Allocate Emission Rights?

Possible guiding ethical principles:

• Egalitarian
• Ability to pay
• Historic responsibility (or polluter pays principle)
• Sovereignty

Adopted from den Elzen and Lucas, 2005
How to Allocate Emission Rights?

Possible allocation rules e. g.:

- Contraction & convergence (C&C)
- C&C including historic emissions (C&C hist resp)
- Common but differentiated convergence (CDC)

Höhne et al., 2006
Will permit trade create new rent-seeking economies?
Technology and Rent-Seeking

• How are results influenced by assumptions on
  – the initial permit allocation
  – Type of climate target

• Understand and quantify domestic effects, energy trade effects, permit trade effects on regional mitigation costs by a new economic decomposition method

→ We need a model with an appropriate representation of inter-regional interactions and high technological resolution.
Determinants of Regional Mitigation Costs

\[ \Delta C = D + T - \int_{t_0}^{T} \exp(-\rho t)(A(t) - E(t))p(t)dt \]

- Domestic Effect
- Energy Trade Effect
- Allocation
- Emissions
- Carbon Prize
- Carbon trade balance
- Carbon Trade Effect

Lüken et al. (2009)
Effects on Regional Mitigation Costs

Influence of Initial Permit Allocation:
- pure redistribution!
- 2nd theorem of welfare:
  - free flow of capital
  - \( \rightarrow \) separability of equity and efficiency

\[
\Delta C = D + T - \int_{t_0}^{T} \exp(-\rho t) (A(t) - E(t)) p(t) dt
\]

Lüken et al. (2009)
Effects on Regional Mitigation Costs

Influence of Initial Permit Allocation:

pure redistribution!

2\textsuperscript{nd} theorem of welfare:
free flow of capital
→ separability of equity and efficiency

\[
\Delta C = D + T - \int_0^T \exp(-\rho t)(A(t) - E(t)) p(t) dt
\]

\(\Delta C\): Consumption loss [$]

\(\Delta C\): Carbon trade balance

\(\bigcirc\): Carbon trade balance = 0

Lüken et al. (2009)
Effects on Regional Mitigation Costs

\[ \Delta C = D + T - \int_{t_0}^{T} \exp(-\rho t)(A(t) - E(t))p(t)dt \]

Influence of Technology:
More technological flexibility \( \rightarrow \)
- Global costs decrease
- Regional costs generally decrease

But: Pareto optimal sharing of emission changes!

Lüken et al. (2009)
Effects on Regional Mitigation Costs

\[ \Delta C = D + T - \int_{t_0}^{T} \exp(-\rho t)(A(t) - E(t))p(t)dt \]

Lüken et al. (2009)
Decomposition of Cumulative Consumption Effects

• Macro Economic Budget (cumulated over time):

\[
\sum_t (Y - X_G) = \sum_t (C + I + G_{ESM}) \quad \text{for all regions}
\]

• Intertemporal Trade Balance:

\[
\sum_t (p_G X_G + p_E X_E + p_P X_P) = 0 \quad \text{for all regions}
\]

• Combine (1) and (2), calculate aggregate differences of policy scenario and reference scenario for all regions:

\[
\Delta C = \Delta Y - \Delta I - \Delta G_{ESM} + \Delta X_E + \Delta X_P
\]

\(\Delta C\) domestic effect \(\Delta X_E\) energy trade effect \(\Delta X_P\) permit trade effect

(subtract extraction costs from energy trade effect)

Lüken et al. (2009)
Scenarios

- *default scenario*: 2 °C climate target
- *nucfix*: nuclear restricted to reference scenario level
- *renewfix*: renewables restricted to reference scenario level
- *ccsmin*: CCS restricted to 100 GtC cumulated
Results: Domestic and Energy Trade Effect

- Domestic effects dominate:
- GDP loss
- Shift from fuel costs to investment costs
- Trade effects:
  More costs for Gas and Uranium imports

Lüken et al. (2009)
Results: Domestic and Energy Trade Effect

- Lower technological flexibility:
- mainly higher GDP losses
- Modulation of trade effects

Lüken et al. (2009)
Results: Domestic and Energy Trade Effect

- Stronger trade effects:
  - devaluation of Coal and Oil endowments
  - revaluation of Gas and Uranium endowments

Lüken et al. (2009)
Results: Domestic and Energy Trade Effect

- Lower technological flexibility:
- Modulation of trade effects
- Changed shares in global reduction efforts
  e.g.: RUS, ccsmin

Lüken et al. (2009)
Regional Emissions (cumulative)

Lüken et al. (2009)
Results: Permit Trade Effect

- linear relation
- huge (absolute) numbers

→ Strong redistribution implied by common allocation schemes

Lüken et al. (2009)
Results: Combined effects

Lüken et al. (2009)
Results: Combined effects

- Greater impact of allocation scheme, when technological flexibility is lower
- Incentive for industrialized regions to promote technology
- Exceptions (e.g., RUS, ccsmin): lower share in global reduction effort

Lüken et al. (2009)
Rent Income and Technology: Conclusions

• Trade effects matter for the distributive effects of mitigation:
  – Costs of fossil energy exporters can largely be attributed to the devaluation of their endowments

• Assumptions on the availability of low-carbon technologies have a significant impact
  – on regional shares in the global emission reduction effort
  – on revenues from energy and permit trade due to a modified carbon price

Lüken et al. (2009)
Distributive Effekt: Policy Implications

- Higher technological flexibility
  → generally leads to lower redistributions
  → less conflicts about permit allocation scheme

- Incentives for industrialized regions to promote the feasibility of low-carbon technologies, especially under allocation schemes that generate high redistributions

→ A broad portfolio of low-carbon technologies facilitates international agreements on a permit allocation scheme, which is a cornerstone of a stringent global climate policy.

Lüken et al. (2009)
“The European Commission is preparing to call on the United States to create a trans-Atlantic system of carbon trading”

Source: Flachsland (2009)
Regulating Carbon Markets – ICAP

ICAP Political Declaration (2007):

“(…) an expert forum to discuss relevant questions on the design, compatibility and potential linkage of regional carbon markets”

- Public workshops on MRV, auctioning in 2008
- Exchange between regional regulators
- Develop best practice
- Nucleus for international regulatory body alongside UNFCCC?
The Cost of Delay…

…and the case for early action

Consumption Losses [%]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>WORLD</th>
<th>EU-27</th>
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<tbody>
<tr>
<td>DELAY 2020</td>
<td></td>
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<tr>
<td>EU 2010, others 2020</td>
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<td>Annex I 2010, others 2020</td>
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<td>IND+CHN+Annex I 2010</td>
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<tr>
<td>all 2010</td>
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Delay of Participation

- Incomplete participation increases the global costs of mitigation

- Incomplete participation can increase the long-term costs not just for early entrants but also for late entrants

- Mechanisms to bring international action closer to full participation can decrease costs for all involved

- Clear expectation about future targets lead to near-term reductions in preparation and lower costs for the first mover
Coverage: Broad is Beautiful

- Full sectoral coverage optimal
- Broadening coverage enhances efficiency
- Small sources can be included upstream
- Exclude uncertain / unverifiable sources
- Clear message over long-term development of cap and coverage strengthens investor confidence

Total EU-27 greenhouse gas emissions by sector, 2006
(Source: European Environment Agency)

- Energy industries (incl. fugitive emissions) 32.7%
- Industry (energy & process related) 21.0%
- Households and services 14.8%
- Agriculture 9.2%
- Transport 19.3%
- Waste 2.9%
- Solvents 0.2%

EU ETS covers 2.02 GtCO2 or ~40% of total
Broadening Sectoral Coverage Lowers Abatement Costs

Goal: Achieve a given abatement level $A$

- If coverage is limited to electricity and manufacturing:
  \[ A = A_E + A_M \text{ at price } P \]
- If coverage is extended to include buildings:
  \[ A = A_E^* + A_M^* + A_B \text{ at lower price } P^* \]
How to allocate permits to regulated firms:

i) ‘grandfathering‘ (=giving away for free)

ii) auctioning

iii) mix of both
The EU Emissions Trading System – Reform

1. Auction allowances!

2. Include all sectors

3. Price carbon where substitution possibilities are the highest, up-stream systems are beneficial

4. Include more regions – towards a global carbon market
Architecture of a Global Contract

Global Contract

Effectiveness – Efficiency – Equity

- Global Carbon Market
- Technology
- Reducing Deforestation
- Adaptation
R&D-Investment in Energy Technologies

Source: Updated version of IPCC (2007), AR4
What’s the Problem?

• Carbon price should provide all necessary incentives:
  – Low-carbon technologies become more profitable
  – Firms will develop technologies to reap these profits

• Only if
  – Carbon price is fully credible
  – No other market failures exist

• See, for example, results from REMIND-R
What’s the Problem? (2)

• Carbon pricing alone will not be sufficient to reduce emissions on the scale and pace required as:
  – Future pricing policies of governments and international agreements cannot be 100% _credible_
  – The _uncertainties_ and risks both of climate change and the development and deployment of the technologies to address it are of such scale and urgency that the economics of risk points to policies to support the development and use of a portfolio of low-carbon technology options
  – The _positive externalities_ of efforts to develop them will be appreciable and the time periods and uncertainties are such that there can be major difficulties in financing through capital markets

_Source: Stern (2007)_
What to Do?

• Governments can help to foster changes in industry and the research community through a range of instruments:
  – Carbon pricing, through carbon taxes, tradable carbon permits, carbon contracts and/or implicitly through regulation will itself directly support the research for new ways to reduce emissions
  – Raising the level of support for R&D and demonstration projects, both in public research institutions and the private sector
  – Support for early stage commercialisation investments in some sectors
Technology R&D Expenditures

- Oil price shocks of the 1970s boosted technology R&D
- But: There is no evidence yet of a similar response from the latest price surges
- A technology R&D response to the challenge of climate mitigation has not occurred. Energy technology R&D has remained roughly constant over the last 15 years despite the fact that climate change has become a focus of international policy development
- Energy technology R&D is one policy lever that governments have for encouraging a more climate friendly capital, a strengthened publicly funded commitment to technology development could play an important role in altering the trends in GHG emissions

Source: IPCC AR4, Ch1
Public Funded R&D Expenditures for Energy

• Declining energy R&D investments: Energy in general
Public Funded R&D Expenditures for Renewable Energy

- Declining energy R&D investments: Renewable energy
Architecture of a Global Contract

[Diagrame showing a structure labeled 'Global Contract' with pillars labeled 'Global Carbon Market', 'Technology', 'Reducing Deforestation', and 'Adaptation', and the categories 'Effectiveness', 'Efficiency', and 'Equity']
Market Prices for staple foods and crude oil monthly averages 1991 - 2008

annual price increase: 13.4%

Source: IMF; FAO International Commodity Prices
Reducing Deforestation: Fossil vs. LUCF CO₂ Emissions

CO₂ emissions per person and year, 1950 - 2003

CO₂ emissions from fossil fuel combustion and cement production, and including land use change (kg C per person and year from 1950 - 2003)

-1000 - 0  1000 - 2000  0 - 100  2000 - 5000  100 - 1000  5000 - 15000

Emissions per year from fossil fuel combustion and cement production

Emissions per year from land use change
A mechanism for Avoided Deforestation has to:

- Ensure additionality, permanence & co-benefits
- Avoid leakage
- Guarantee fair sharing of benefits and costs

Political framework and design options:

Until now there are no incentives for avoiding tropical deforestation

1) Carbon market integration
2) Fund-based schemes
3) Hybrid schemes
Mitigation costs of avoided deforestation

Accounting (bottom-up) (e. g. Grieg-Gran 2007)
50% reduction in deforestation $\rightarrow$ $5-10$ billion yr$^{-1}$

Forest models (top-down) (e. g. Kindermann et al. 2008)
10% reduction in deforestation $\rightarrow$ $0.4-1.7$ billion yr$^{-1}$
50% reduction in deforestation $\rightarrow$ $17.2-28.0$ billion yr$^{-1}$

Carbon price (2030) necessary to generate
10% reduction in deforestation: $3.17$ $\text{t}^{-1}$ CO$_2$
50% reduction in deforestation: $15.58$ $\text{t}^{-1}$ CO$_2$

(Source: Kindermann et al. 2008)
Architecture of a Global Contract

Global Contract

Effectiveness – Efficiency – Equity

Global Carbon Market
Technology
Reducing Deforestation
Adaptation
Mitigation and Adaptation

- **WATER**: Increased water availability in moist tropics and high latitudes; Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes; Additional people with increased water stress.
  - 0.4 to 1.7 billion to 1.0 to 2.0 billion to 1.1 to 3.2 billion.

- **ECOSYSTEMS**: Increasing amphibian extinction; About 20 to 30% species at increasing high risk of extinction; Major extinctions around the globe; Increased coral bleaching; Most corals bleached; Widespread coral mortality; Terrestrial biosphere tends toward a net carbon source, as ~15%; Increasing species range shifts and wildfire risk; 40% of ecosystems affected.

- **FOOD**: Crop productivity; Low latitudes: Decreases for some cereals; Mid to high latitudes: Increases for some cereals; All cereals decrease; Decreases in some regions.
  - Mid to high latitudes.

- **COAST**: Increased damage from floods and storms; Additional people at risk of coastal flooding each year: up to 3 million to 2 to 15 million; About 30% loss of coastal wetlands.

- **HEALTH**: Increasing burden from malnutrition, diarrhoeal, cardio-respiratory and infectious diseases; Increased morbidity and mortality from heatwaves, floods and droughts; Substantial burden on health services; Changed distribution of some disease vectors.

- **SINGULAR EVENTS**: Local retreat of ice in Greenland and West Antarctic; Long term commitment to several metres of sea level rise due to ice sheet loss; Leading to reconfiguration of coastlines worldwide and inundation of low-lying areas; Ecosystem changes due to weakening of the meridional overturning circulation.

**Global mean annual temperature change relative to 1850-1899 (°C)**
Architecture of a Global Contract

- Global Carbon Market
- Technology
- Reducing Deforestation
- Adaptation