Uncertainty, cost-effectiveness and environmental safety of carbon trading markets

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Land use & agriculture **Forestry** **Integrated modeling**

Introduction

International emission trading (IET) is an important economic (market) instrument for enhancing environmental security

IET is likely to gain further popularity especially after Copenhagen

Original objective of IET – to reduce the costs of GHG emissions reductions, i.e., Parties with high emission reductions costs may buy emissions from Parties with lower emission reduction costs within prescribed targets to fulfill environmental safety goals

This is a bilateral emission trading (exchange) procedure driven by cost minimizing and environmental safety criteria without a need for a market

ET has been implemented through market similar to financial markets, i.e.,

- Price-driven
- Current (spot or "disequilibrium") prices are affected by uncertainties;
- Market is volatile;
- Without accounting for future expectations;
- May be speculative;
- May have nothing in common with e. reduction targets and cost-minimization;
- May not guarantee environmentally safe solutions

Controlling environmental security

Two ways to control emissions trading:

Centralized command and control:

If the central agency is fully informed about emissions and abatement cost – meeting the standards in a cost-effective way is a straightforward problem, i.e., solve primal model of emissions reduction at minimal costs sbj. to env. targets

Decentralized:

in the absence of information, solution has to be found in a decentralized manner

1. Bilateral emission trading – uncertainty about cost functions
   -- driven by abatement costs without revealing information about cost functions;
   -- no reason to cheat about cost functions;
   -- cost-effective mutually beneficial solutions;
   -- forward-looking strategies over a planning horizon;
   -- explicit treatment of emissions uncertainties – expectations or pdfs;
   -- new technologies with (possibly) "increasing returns" cost functions

2. Price-driven carbon trading markets

Price based markets achieve cost-effective and environmentally safe solution if they solve the dual model. In the presence of uncertainties and nonlinear cost functions, the solution of the dual problem requires full information.

"Duality Gap"

Why markets may not produce cost-effective env. friendly solution ?

-- For each party, the primal problem is to minimize costs and achieve emission reduction

-- Market "solves" a dual problem – maximize price sbj. to constraints

-- There may be the duality gap – the solution of the price maximizing dual problem does not equal to the solution of primal problem.

The solution of the dual problem may not be possible to find (no information)

May not exist under uncertainties and non-smooth abatement cost functions

Dual: $$\max_{\lambda} \min_{x} \left[f_0(x) + \sum_i f_i(x)\lambda_i \right]$$

Primal: $$\min_{x} \max_{\lambda \geq 0} \left[f_0(x) + \sum_i f_i(x)\lambda_i \right]$$

$$\min_{x} \left[\max_{\lambda \geq 0} \left[f_0(x) + \sum_i f_i(x)\lambda_i \right] = \begin{cases} f_0(x), f_i \leq 0 \\ \infty \end{cases} \right]$$

Emissions uncertainties

Uncertainties in abatement costs; **Natural uncertainties;**
Emissions measurements; **Emissions monitoring;**
Conversion factors; **Reporting;** **Accounting, …**

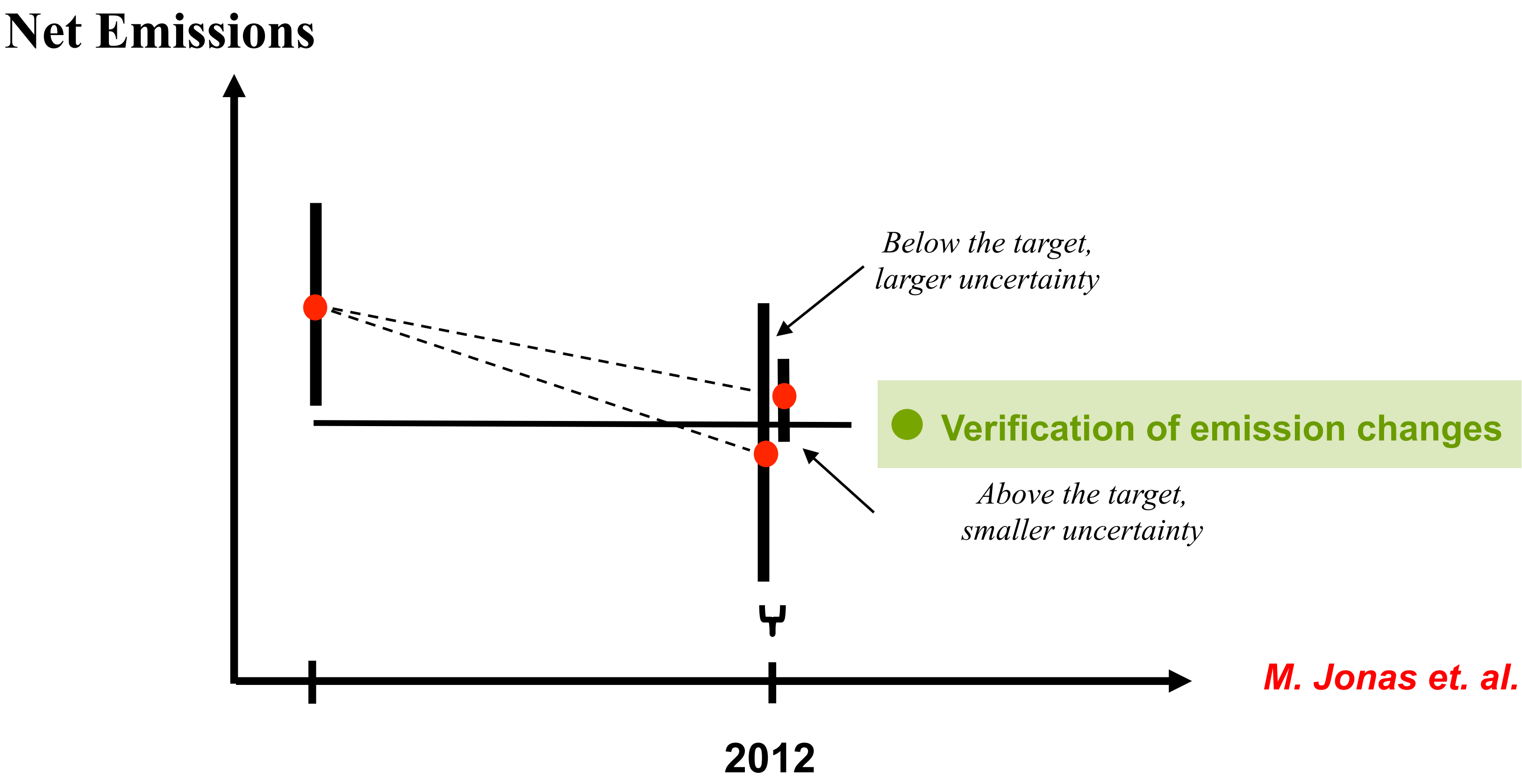
- ✓ Robust emission trading requires verifiability of tradable products enabling their reality

- ✓ Uncertainties are not accounted for in emission trading markets: volatility, crashes

" Carbon prices in the European Union crashed and caused instabilities in late April 2005 after the Czech Republic, Estonia, France, the Netherlands and Sweden all reported lower than anticipated emissions"
(Energy Business Review, May, 2006)

- ✓ Irreducible uncertainties – the need for robust forward looking (two-stage) solutions
- ✓ Stochastic multi-criteria (multi-agent) optimization, stochastic minimax approach

The role of uncertainties and their representation



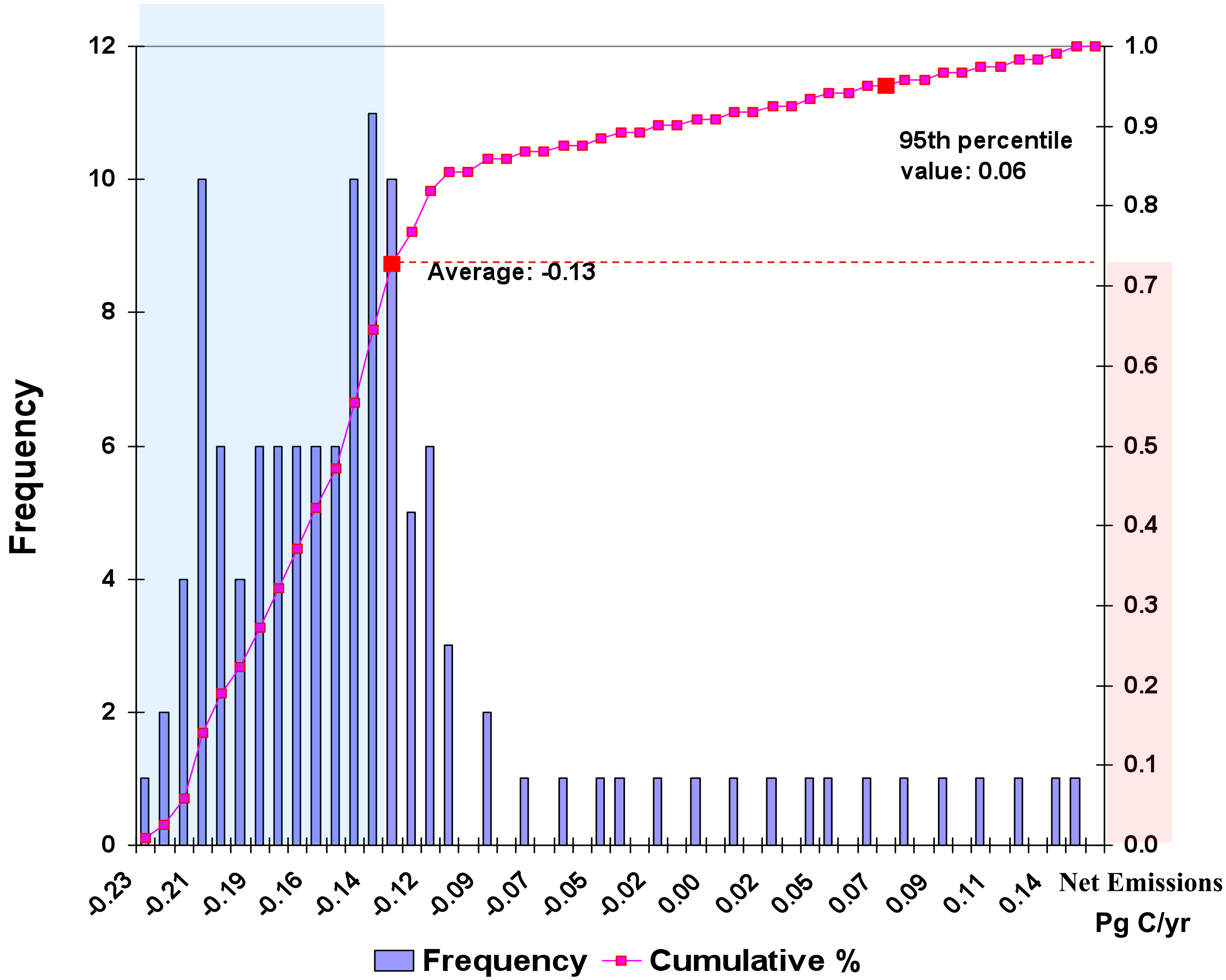
✓ **Interval** (symmetrical) uncertainty representation is practices by IPCC

✓ Uncertainties usually have more complex spatial and temporal shapes and characteristics. Interval representation may be misleading and costly

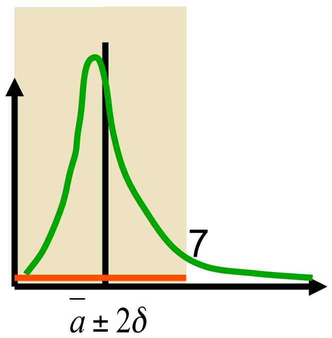
Data source: http://lgmacweb.env.uea.ac.uk/lequere/co2/carbon_budget.htm

Slow dynamics vs large variability:

Net terrestrial uptake, 1960-1970

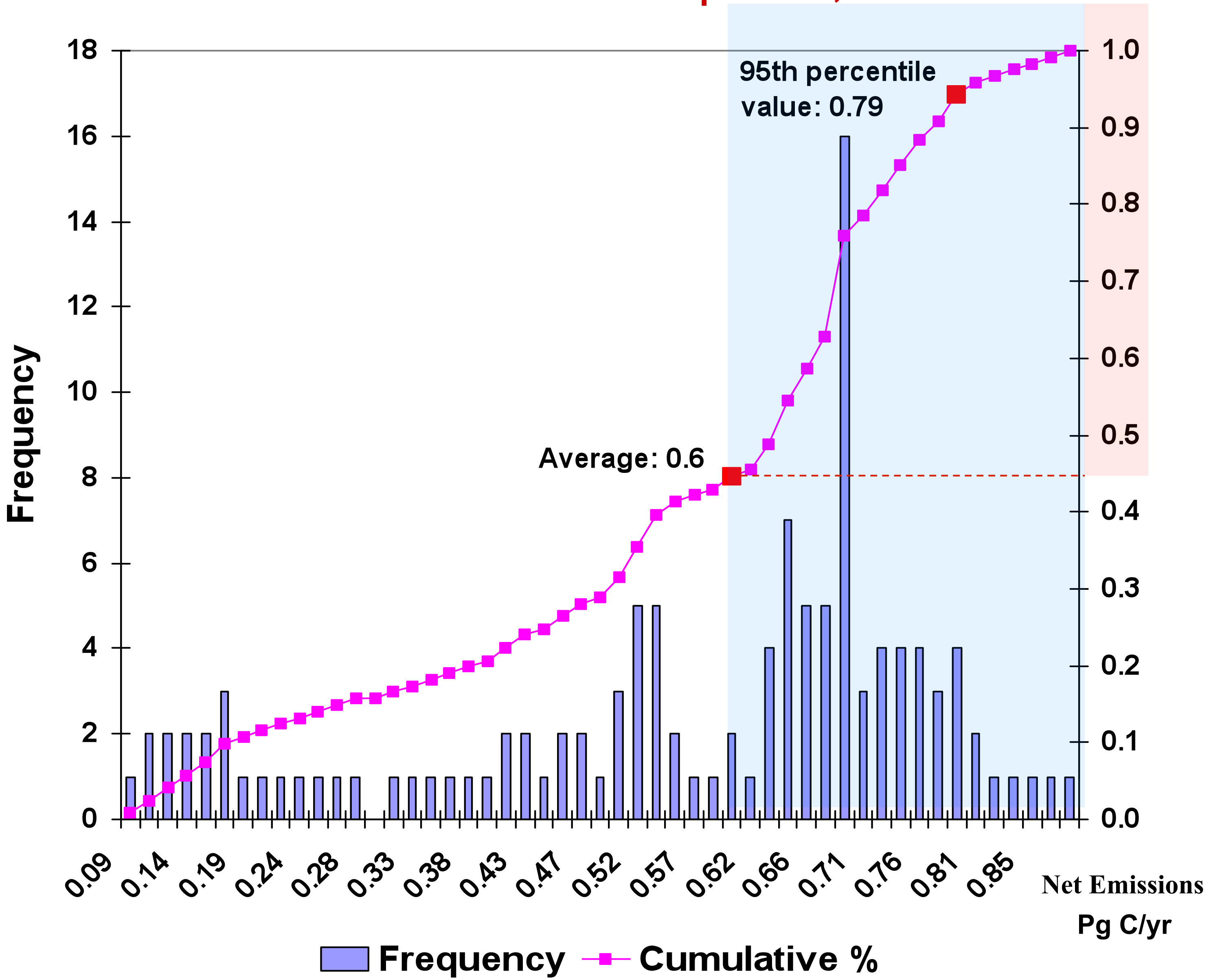


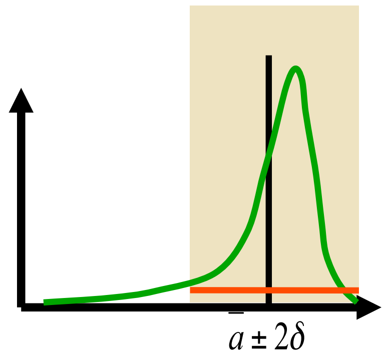
More emissions below average !



Slow dynamics vs large variability:

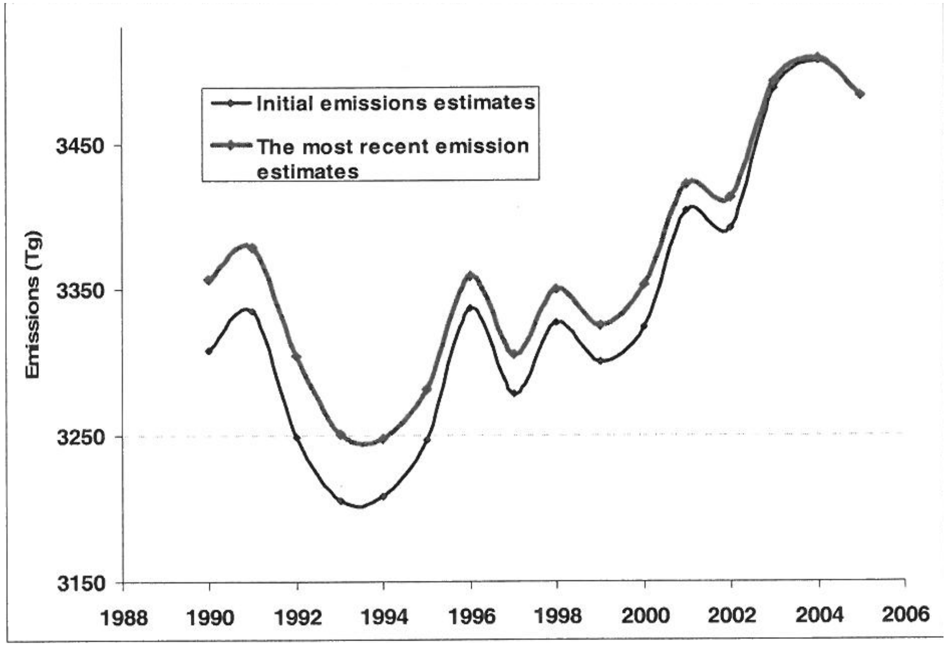
Net terrestrial uptake, 1985-1995





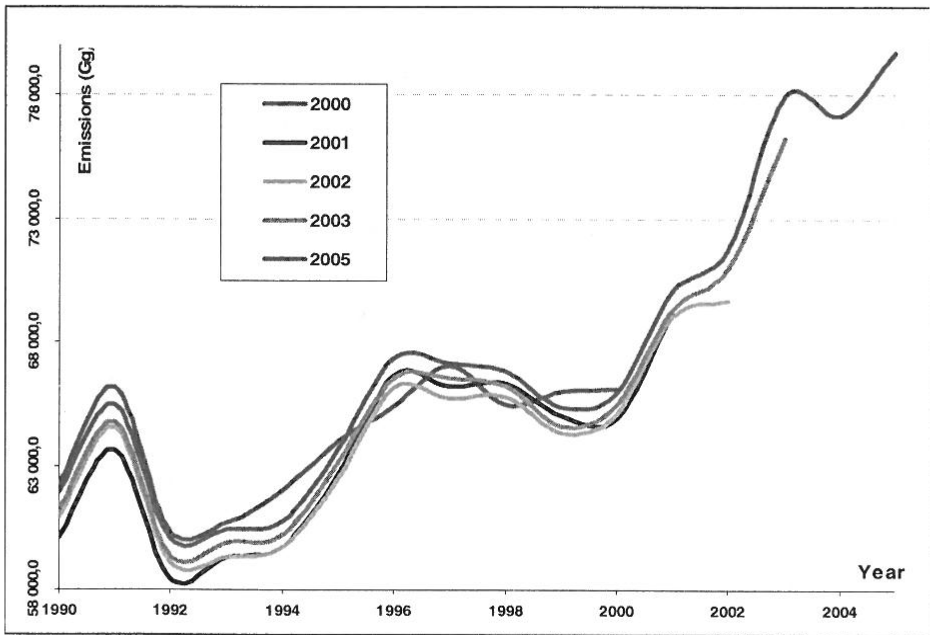
More emissions above average !

Emissions uncertainties: the need for forward looking two-stage solutions



EU-27's CO2 emissions estimated initially and revised in 2005.
Hamal, IIASA IR, NIR 1999-2007.

Austrian's emissions estimated in 2000 and revised in 2001, 2002, 2003 and 2005
Hamal IIASA-IR, Austrian NIR 2000-2007.



- ✓ Here, only the "best" estimate is revised
- ✓ No uncertainties representation

Basic emission trading model: two problems

Problem 1: Individual problem.

Minimize cost functions: $f_i(y_i) = \min_{u_i, x_i} \left[c_i(x_i) + d_i(u_i) \right]$

Under constrains: $x_i + u_i \leq K_i + y_i$

Costs of emissions red.: $c_i(x_i)$

Costs of uncertainties red.: $d_i(u_i)$

Emissions level x_i

Uncertainties level: u_i

At given level of emissions permits: y_i

Problem 2: Social welfare – social planner (Principal agent)

Find optimal vector of permits $y = (y_1, \ldots, y_n)$

Minimizing total or social costs $F(y) = \sum_{i=1}^{n} f_i(y_i)$

Under limited resources: $\sum_{i=1}^{n} y_i = 0$

Emission trading: bilateral procedure

There is no central planner that knows the cost functions of the Parties.
We show that the minimum value of the social goal function is found via bilateral trading:

$$F(y) = \sum_{i=1}^{n} f_i(y_i)$$

The bilateral procedure finds equilibrium vector

$$y = (y_1, \ldots, y_n)$$

Out of Lagrangian $\sum_{i=1}^{n} f_i(y_i) - \lambda \sum_{i=1}^{n} y_i$

Equilibrium condition $f_i'(y_i) = \lambda$ for all Parties ***i***

Bilateral emission trading

Party 1 buys emission permits ("decreases" emissions) $y_i^{k+1} = y_i^k + \Delta_k$

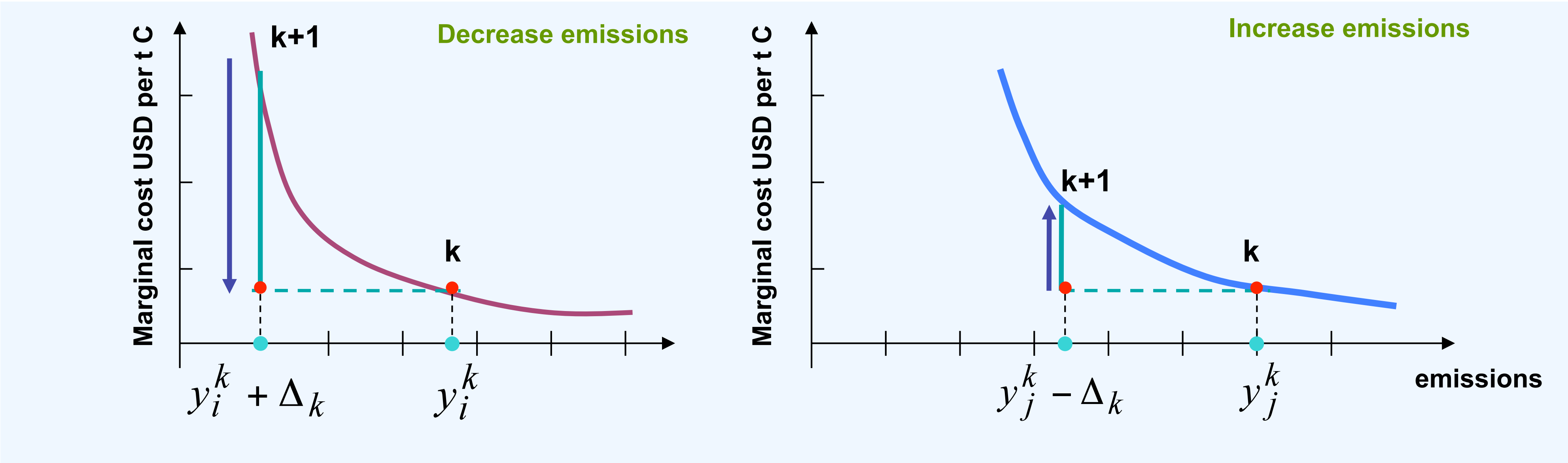
Party 2 sells emission permits ("increases" emissions) $y_j^{k+1} = y_j^k - \Delta_k$

The new distribution of permits reduces costs of ***i*** more than increases costs of ***j***

$$f_j(y_j^k) - f_j(y_j^{k+1}) < f_i(y_i^{k+1}) - f_i(y_i^k)$$

y is a level of permits

Hence, ***i*** is able to compensate ***j*** for the increased costs in a mutually beneficial way



Cost functions *f* explicitly treats uncertainties:

- may have form of expectations;
- include safety constraints on compliance with emission targets;
- include direct costs for emissions reductions and for uncertainties reduction

Emission trading with uncertainties: CVaR and VaR risk measures

- ✓ Representation of deterministic and “stochastic” emissions uncertainties
- ✓ Environmental security (safety) constraints account for critical percentiles

$$x_i + u_i \le K_i + y_i \qquad \text{vs} \qquad P\left[\varepsilon_i(t_2, x_i, \omega_i) \le K_i + y_i\right] \ge Q_i$$

$$P\left[x_i + \xi_i(x_i, \omega_i) \le K_i + y_i\right] \ge Q_i$$

$$P\left[\xi_i(x_i, \omega_i) \le z\right] \ge Q_i$$ - critical percentile of emissions df

$$x_i + u_i \le K_i + y_i \qquad u_i \le z_i(x)$$

- ✓ Bilateral emission trading is a stochastic quasigradient procedure
- ✓ Derives stochastic equilibrium solution which satisfies safety (security) constraints

Stochastic minimax

Problem 1: Individual problem.

$$f_i(y_i) = \min_{x_i u_i} E\left[c_i(x_i, \omega) + d_i(u_i, \omega)\right]$$

$$x_i + u_i \le K_i + y_i$$

$$P\left[x_i + \xi_i(x_i, \omega_i) \le K_i + y_i\right] \ge Q_i$$

$$P\left[\xi_i(x_i, \omega_i) \le z\right] \ge Q_i$$

$$Q_i v_i + E\max\{0, x_i + \xi_i(x_i, \omega_i) - K_i - y_i - v_i\} \qquad g_i(x_i, y_i)$$

$$v_i \ge 0$$

$$v_i^* \qquad P[x_i + \xi_i(x_i, \omega_i) \le K_i + y_i + v_i] = Q_i$$

$$f_i(y_i) \qquad f_i(y_i) = \min_x\left[E c_i(x_i, \omega) + g_i(x_i, y_i)\right]$$

Computerized Web-based Multi-Agent Decentralized Trading System

- ✓ The problem is that there is no perfect market which may implement this approach

- ✓ Computerized (Web-based) Multi-Agent Decentralized Trading System

  - Distributed computer network connecting computers of parties with the computer of a central agency

  - Parties anonymously store information on cost functions and other characteristics of the underlying optimization model

  - The computer of the central agency anonymously "negotiates" with the computers of these partners a proper equilibrium solution

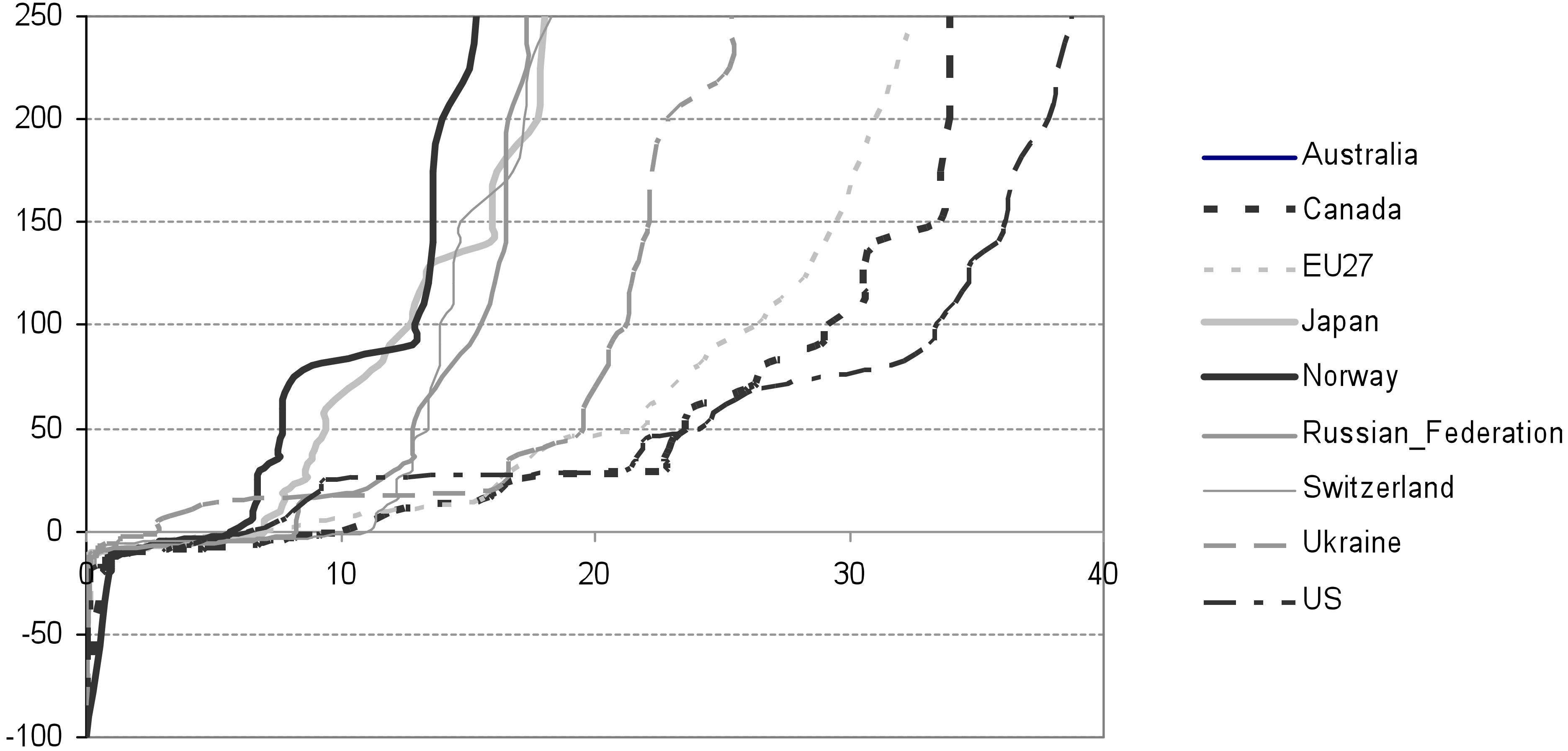
  - Web-based MATS can be easily implemented without revealing parties' private information

The MATS allows an equilibrium solution to be found that can then be implemented in reality

The role of uncertainties in bilateral trading

Uncertainties affect equilibrium solution

Compare two solutions: deterministic and robust



The role of uncertainties in bilateral trading

Recent studies analyze the role of uncertainties in bilateral trading of carbon emissions

Studies include several major countries : USA, EU, … , Russia, Ukraine

	Emissions 1990	**Emissions 2009**	**Baseline 2020**	**Pledges**	**Unc. (% targets)**
USA	6,135.20	7,017.30	422.3	5,898.50	15
Australia	416.2	536.1	573.1	470.4	10
Canada	592.3	720.6	765.5	576.5	15
EU27	5,564.00	5,129.60	4,670.60	4,451.20	15
Japan	1,272.10	1,340.10	1,199.10	1,154.40	15
Russia	3,326.40	2,190.20	2,481.00	2,661.10	25

Unreported emissions as percentage of targeted emission levels.

Data: IPCC, (Nilsson et al.), (Klaassen and Nentjes), Obersteiner, GAINS and POLES models, Godal et. al., Nahorski and Horabik

The role of uncertainties in bilateral trading

	BAU20	Target20	Emiss	Trades	Marg.cost emiss
USA	6969	5899	6461.5	563.1	22.5
Australia	573	470	412.8	-57.6	22.5
Canada	766	577	652.1	75.6	22.5
EU27	4671	4451	4493.7	42.8	22.5
Japan	1199	1154	1298.7	144.3	22.5
Russia	2481	2661	1892.7	-768.2	22.5

	BAU20	Target20	Emiss	Trades	Marg.cost emiss	Marg.cost uncert
USA	6969	5899	6461.5	61.1	84.2	84.2
Australia	573	470	412.8	-37.4	84.2	84.2
Canada	766	577	652.1	124.1	84.2	84.2
EU27	4671	4451	4493.7	54.1	84.2	84.2
Japan	1199	1154	1298.7	196.1	84.2	84.2
Russia	2481	2661	1892.7	-398.0	84.2	84.2

Conclusions

Two approaches to emission trading are compared:
current price-drive market approach and a decentralized bilateral emission trading procedure.

Market-based emission trading may be enhanced with a bilateral emission trading scheme to ensure risk-free, cost-effective
and sustainable way for emission trading partners to reach their emission reduction targets.

The proposed approach takes long-term perspectives on emission trading by using rational expectations about new emission reduction technologies and safety regulations of the environmental targets.

The motivation of the research is to create a web-based MATS for decentralized collective regulation of trades by central agency

Web-based MATS creates a basis for successful and fair implementation of environmentally friendly Kyoto and post-Kyoto agreements.

Without uncertainties, verifiability of emissions was not required

If uncertainties are included and verifiability is required (to ensure targets), verifiability works as discounting of reported emissions to detectable levels

Explicit representation of uncertainties allows to develop a stochastic emission trading model with explicit introduction of appropriate risk measures to control the safety of emission reduction targets (e.g., post-Kyoto pledge targets). This type of safety constraints is typical for pollution control, financial applications, stability regulations in the insurance industry and catastrophic risks management.

Since the concept of safety constraints discounts emission changes to detectable levels, this provides incentives to reduce uncertainty before trading. This significantly affects the trade equilibrium state, i.e., this state cannot be achieved without explicit introduction of the safety constraints. In contrast to “black-and-white” uncertainties characterized by intervals, the proposed stochastic model aims to reduce underestimating and overestimating costs by using additional information on likelihoods of uncertainties which can be characterized by precise or/and imprecise probabilities and sets of potential scenarios.

No uncertainties: Emissions, marginal costs and total costs before and after trade

	USA	EU	Japan	CEE	Russia	Ukraine	Total
Emissions (Mt C)							
Kyoto target	1,325	867	295	267	650	178	3,582
BAU	1,690	1,097	404	203	475	130	3,999
After trade	1,487	1,003	373	187	418	114	3,582
Traded	162	136	78	-80	-232	-64	0
Marginal costs (USD per tC)							
Before trade	85	133	248	0	0	0	
After trade	38.5	38.5	38.5	38.5	38.5	38.5	
Abatement costs (MUSD per yr)							
Em. red. costs no trade	13,468	13,032	10,873	0	0	0	37,373
Em. red. costs after trade	3,907	1,722	556	308	915	248	7,658
Total savings after trade							29,698

Emissions, marginal costs and aggregate costs after all trades with imperfect observation of emissions

	USA	EU	Japan	CEE	Russia	Ukraine	Total
Emi							
Reported	1,193	871	333	154	376	103	3,031
Unreported	100	144	38	52	170	47	551
Total emissions	1,293	1,016	371	206	547	150	3,582
Amount traded	-32	149	76	-61	-103	-28	0
Marginal costs (USD per tC)							
Of emission reduction	129.3	129.3	129.4	129.4	129.4	129.3	
Of monitoring	129.3	129.3	129.4	129.4	129.4	129.3	
Costs (MUSD per year)							
Emission reduction costs	27,660	12,446	3,801	3,001	4,288	1,159	52,355
Monitoring costs	2,766	2,489	570	750	1,287	348	8,210
Total costs (excl. permits)	30,426	14,935	4,371	3,751	5,575	1,507	60,565
Total savings due to trade							35,600