Mitigation costs and potentials in agriculture

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30 March 2006 - CIHEAM-IAM - Barcelona, Spain

Objectives of the lecture

- To provide an overview of the economic concepts used to address the issue of GHG emissions in agriculture
- To highlight the importance of marginal abatement costs and marginal abatement costs heterogeneity
- To present a modelling approach used to assess marginal abatement costs in EU agriculture
- To discuss the results from this modelling approach and their policy implications

Part I

Methodology for sector evaluation

Methodology for sector evaluation: Outline

Regulation of environmental externalities: An economic approach

- Emissions of pollutants as an *externality*.
- Externalities are characterized by the fact that the actions of one agent directly affect the environment of another agent without being priced.
- Prices do not convey the "right" signal: Environmental "goods" ("bads") are produced in too small (large) quantities.
- In the presence of externalities, general market equilibria are inefficient (The First Theorem of Welfare Economics does not hold).

Externalities: A simple illustration

- Two agents (A and B), one good.
- Agent A produces the good in quantity q.
- Production of the good causes an emission $z(q)$:

$$z(0) = 0,\ z'(.) > 0,\ z''(.) \geq 0$$

- Agent A can reduce his/her emissions. Abatement is denoted

$$a = \bar{z} - z$$

- Reduction in emissions is obtained at a cost $C(a)$:

$$C(0) = 0,\ C'(.) > 0,\ C''(.) \geq 0$$

- Pollution reduces agent B's welfare by an amount $D(z)$:

$$D(0) = 0,\ D'(.) > 0,\ D''(.) \geq 0$$

Unregulated situation

- Abatement is costly for agent A.
- In order to maximize his/her profit, agent A minimizes abatement costs
- $a = 0$, $z = \bar{z}$

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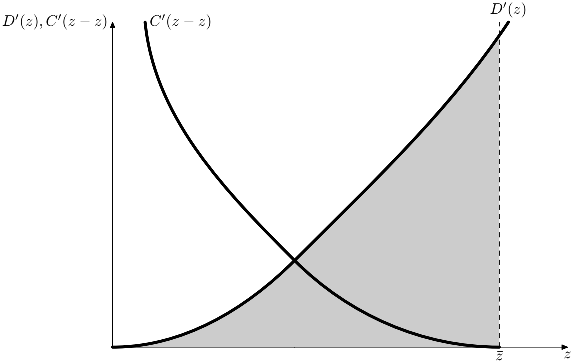
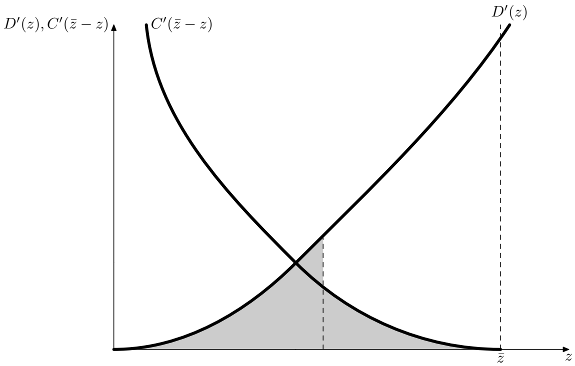
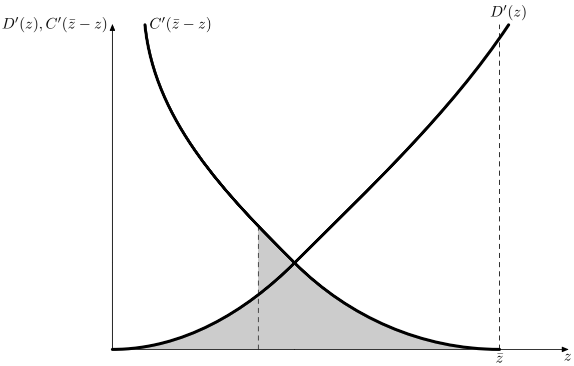


Optimal pollution



Optimal pollution

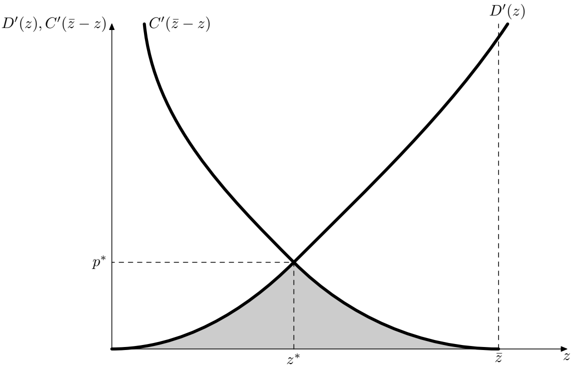


Optimal pollution

Optimum pollution is characterized by

$$\min_z C(\bar{z} - z) + D(z)$$

$$C'(\bar{z} - z) = D'(z)$$



Many polluters

- Assume now that there are n polluters $(i = 1, \dots, n)$
- Each polluter faces abatement costs $C_i(\bar{z}_i - z_i)$:

$$C_i(0) = 0,\ C_i'(.) > 0,\ C_i''(.) \geq 0 \text{ for all } i$$

- The damage depends on *total* emissions $D(Z)$:

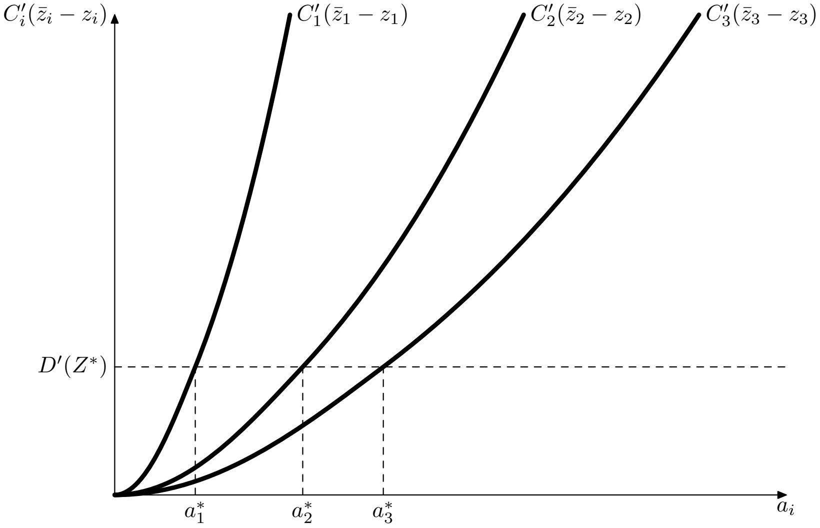
$$Z = \sum_{i=1}^{n} z_i,\ D(0) = 0,\ D'(.) > 0,\ D''(.) \geq 0$$

- The optimal pollution vector $(z_1^*, \dots, z_n^*)$ is solution of

$$\min_{z_1,\dots,z_n} \sum_{i=1}^{n} C_i(\bar{z}_i - z_i) + D(Z)$$

which leads to $C_1'(\bar{z}_1 - z_1^*) = \cdots = C_n'(\bar{z}_n - z_n^*) = D'(Z^*)$

Many polluters (cont'd)



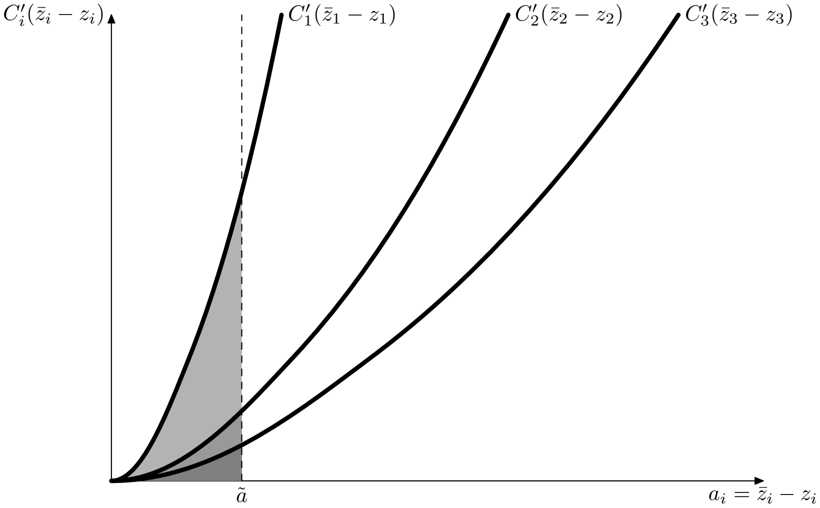
Instruments to solve the externalities problem

- Three broad categories of instruments:
  - Setting standards or targets (command-and-control);
  - Pricing the externality (tax/subsidies);
  - Creating a market (permit market).
- Instruments commonly used are not necessarily economic instruments.
- Economic instruments are intended to correct the wrong signal conveyed by prices in the presence of externalities.
- Optimal pollution level is characterized by:
  - Equal marginal abatement costs among individual polluters (cost-effectiveness).
  - Marginal abatement cost equal to marginal damage (efficiency).
- Emission-based vs practice-based instruments.

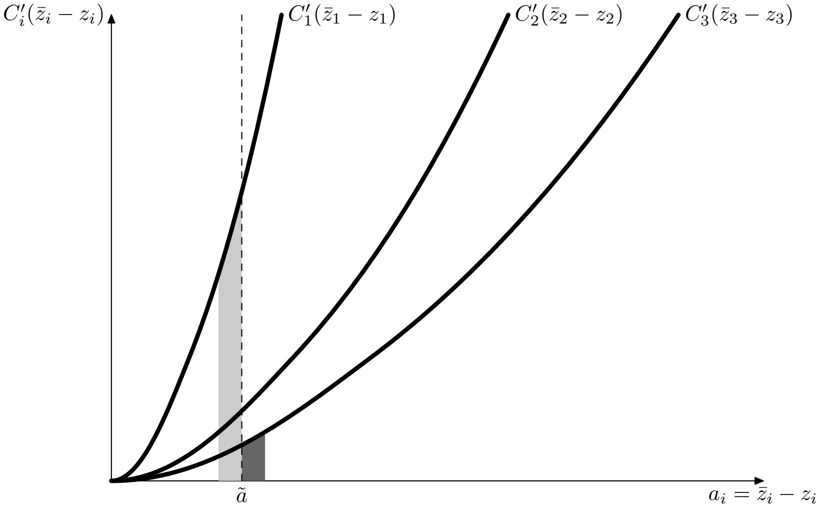
Targets/Standards

- Pollution is too high: Impose emission targets or set standards.
- Centralized solution: The regulator sets targets or standards that agents must comply with.
- Probably the most used instrument.
- If each individual marginal abatement cost curve is known, it is theoretically possible to design differentiated pollution targets that are cost-effective.
- The implementation of the optimum requires to know Z^*, the optimal emission level.
- Emission targets vs process- or practice-standards.
- Uniform standards are cost-ineffective as soon as marginal abatement cost curves are different from one agent to the other.

Cost-(in)effectiveness of uniform standards



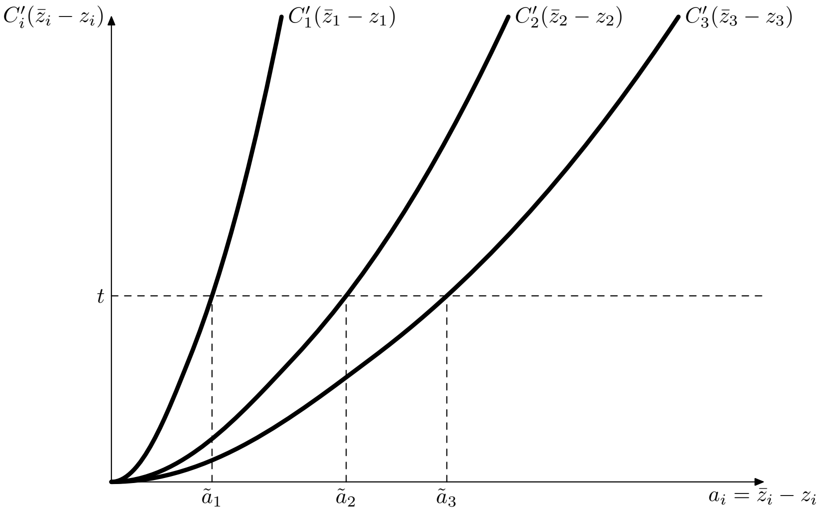
Cost-(in)effectiveness of uniform standards



Emission tax

- The price signal is wrong: Price the externality.
- Decentralized solution: Each agent decides how much pollutant s/he emits given the level of the tax. It is optimal for each agent to emit until the marginal abatement cost equals the tax t.
- Built-in cost-effectiveness: $C_1'(\bar{z}_1 - z_1) = \cdots = C_n'(\bar{z}_n - z_n) = t$.
- The implementation of the optimum requires to know the marginal damage ($t = D'(Z^*)$).
- In case of uncertainty, costs are under control. Total emissions are not.
- Control and monitoring costs.
- Use of tax revenues.
- Emission tax vs input tax.

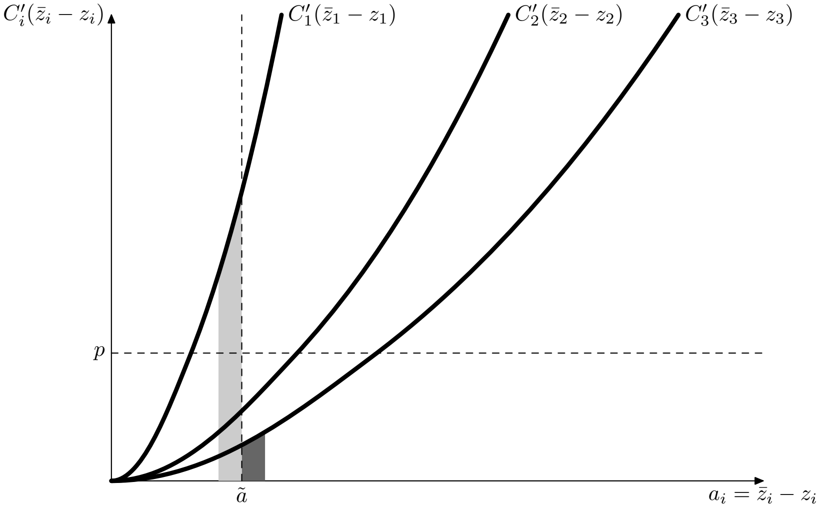
Emission tax (cont'd)



Tradeable emission permits

- One market is missing and property rights are ill-defined: Create a market (and define property rights).
- Decentralized solution: Each agent decides how much s/he emits given the level of the current market price. It is optimal for each agent to emit until the marginal cost of emissions equals the market price p.
- Built-in cost-effectiveness: $C_1'(\bar{z}_1 - z_1) = \cdots = C_n'(\bar{z}_n - z_n) = p$.
- The implementation of the optimum requires to know the optimal emission level Z^*.
- In case of uncertainty, total emissions are under control. Costs are not.
- Transaction costs.
- The issue of the initial allocation of permits.
- Control and monitoring costs.

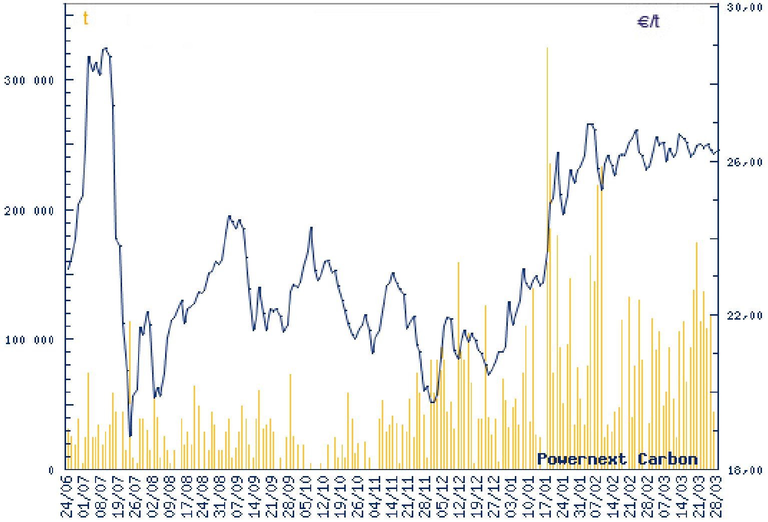
Tradeable emission permits



From theory to practice

- The most commonly used instruments are environmental standards.
- Very few examples of *à la Pigou* taxes (*Landfill Tax* and *Aggregates Levy* in the UK).
- Often, the level of taxes that may have an impact on the environment are loosely related to the marginal environmental damage (see Pearce, 2004).
- In the Climate Change negotiations, the 1992 EU energy/carbon tax failed, clearing the way to quantity- (rather than price-) based instruments.
- An example of tradeable emission permit market: The European Carbon Trading Scheme
  - Introduced in Directive 2003/87/EC, started in 2005.
  - Only the largest emitter (CO_2 emissions).

Trading emission permits (cont'd)



A closer look at abatement costs

- Micro-economic level:
  - Foregone income due to the re-allocation of resources necessary to reduce emissions (holding everything else constant).
  - Cost of adopting more environmental-friendly management practices.
  - Investment in "end-of-the-pipe" technologies.
- Macro-economic level:
  - Price impacts due to changes in production.
  - Structural change (entry/exit in the sector)
  - Incentives to invest in R&D.
  - Changes in international trade (leakage).
- Important distinction between marginal abatement costs and total abatement costs.

Research questions

- Economic mitigation potential in agriculture ($\neq$ technical potential) depends on marginal abatement costs in agriculture relatively to marginal abatement costs in other sectors of the economy.
- How large can be the contribution of agriculture to the fulfilling of the Kyoto commitment?
- How much does it cost to farmers to meet a given abatement target?
- For a given level of incentive (tax), how much abatement farmers are willing to supply?
- How do marginal abatement costs vary across regions and types of farming?
- Where are located the highest economic mitigation potential?
- What are the implications for an optimal mitigation policy design?

A (short) review of modelling approaches

Computable general equilibrium models (e.g., Börhinger et al., 2005).

- Full price impacts endogenously modelled.
- Usually highly aggregated.

Partial equilibrium models (e.g. FAPRI; Saunders and Wreford, 2005).

- Description of the agricultural supply and demand. Agricultural price impacts are endogenously modelled.
- Other drivers (GDP, input prices) are exogenously determined.
- Disaggregated by commodity and countries/regions.

Cost-effectiveness sectoral approach (e.g. Klaasen et al., 2004).

- Detailed description of technologies within a sector. Optimal (cost-minimizing) technology mix is endogenous. Prices are generally exogenous.
- Disaggregated by sectors and countries.

A (short) review of modelling approaches (cont'd)

Regional agricultural models (McCarl, Schneider, 2001; Perez et al., 2003)

- Existing (and alternative) technologies are represented through constraints. Detailed description of the use of quasi-fixed inputs (land-use).
- Agricultural prices can be exogenous or endogenous (link with a partial equilibrium model).
- Disaggregated by commodities and regions (one farm per region).

Farm-type based models (De Cara et al., 2005)

- Description of the technology at the farm level (use of resources, input requirements, crop requirements, CAP-related constraints).
- Prices are usually exogenous (price-taker assumption).
- Highly disaggregated (several farm-types per region).

A (short) review of modelling approaches (cont'd)

	CGE	PE	CE	RAM	FTM
Interactions between sources (substitution, technical feasibility)	+	+	+	+	++
Heterogeneity of abatement costs	-	-	+	+	++
Macro-economic impacts (impacts on prices, on up- and downstream industries, etc.)	++	+	+	+	-

Some concluding remarks

- Importance of marginal abatement cost assessment to determine the optimal (at least cost-effective) level of abatement.
- Highly aggregated modelling approaches tend to overlook the heterogeneity of marginal abatement costs.
- GHG emissions from agriculture involve a variety of sources and gases (methane, nitrous oxide, CO_2): Importance of comprehensive emission accounting.

Part II

Economic Assessment

Economic Assessment: Outline

Agricultural emissions: Background

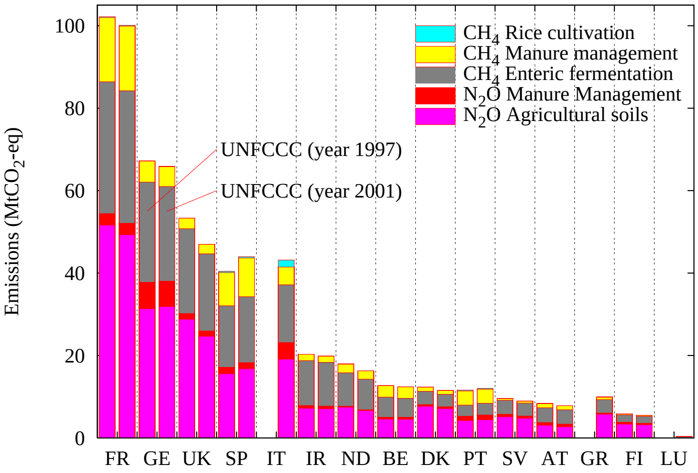
- Agriculture accounts for about 10% of total EU-15 emissions.
- Agriculture is the main emitting sector for non-CO_2 GHGs (methane and nitrous oxide).
- Importance of interactions between methane and nitrous oxide sources (e.g., animal feeding, manure management).
- Agricultural emissions are not included in the ECTS.
- CAP reforms: Shift from income- to environment-oriented support (i.e., from the first to second pillar).

Sources of GHG emissions from agriculture (2001, EU-15)

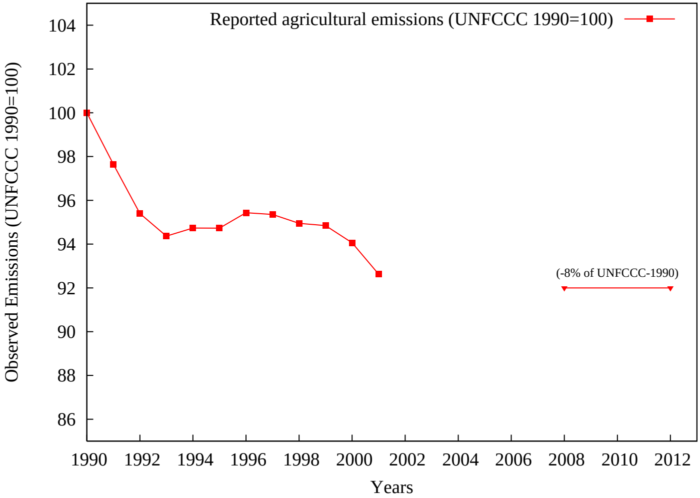
Source	CO_2 (Tg)	CH_4 (Gg)	N_2O (Gg)	CO_2-eq (Tg)	Share in ag emis (%)	Share in tot emis (%)
Agr. soils			635	188	46	5
Manure man.		2,156	70	70	17	2
Enteric ferm.		6,268		144	36	4
Rice cultivation		111		3	1	0
Total agriculture		8,535	704	405	100	10
Total all sources	3,384	15,695	1,111	4,073		100

Based on 2003 EU National Communication for the year 2001
using 2001 GWPs: GWP_{CH_4}=23, GWP_{N_2O}=296,

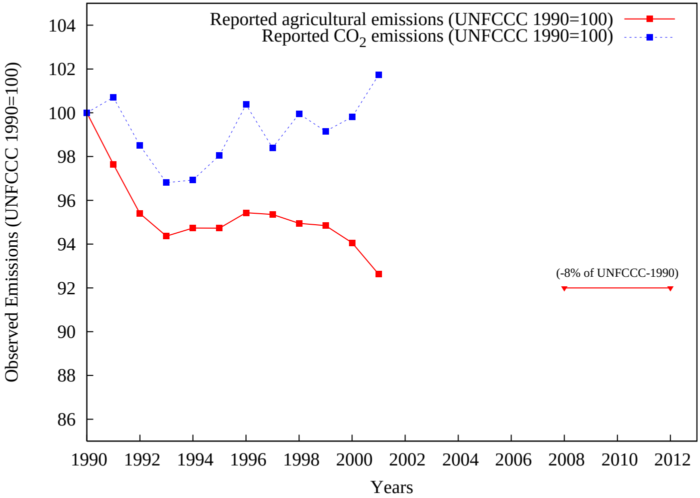
GHG emissions from agriculture by MS (1997 and 2001)



GHG emissions from agriculture (1990–2001, EU-15)

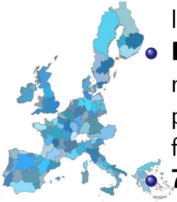


Agriculture vs CO_2 emissions (1990–2001, EU-15)



Overview of the model (De Cara et al, 2005)

A FT based, mathematical programming model of EU agricultural supply.



- **Input data:** FADN (about 60,000 surveyed farms in 101 regions of the EU-15): accountancy data, yields, area, type of farming, altitude zone
- **Typology:** 734 farm-types, covering annual crop and livestock farmers
- **Exogenous variables:** Total area, baseline livestock numbers, yields, prices, variable costs, CAP-related parameters, technical coefficients (agronomic, livestock feeding, emission coefficients, etc.)
- **734 independent models:** MILP, maximization of total gross margin subject to crop area, CAP, livestock feeding, etc. constraints
- **Calibration:** Based on FADN 1997 data
- **Output:** Crop area mix, livestock numbers, animal feeding, emissions

Overview of the model (cont'd)

- The generic (annual) model is a mixed integer linear programming model for farm-type k:

$$\max_{\mathbf{x}_k} \pi_k(\mathbf{x}_k) = \mathbf{g}_k \cdot \mathbf{x}_k \quad (1)$$

$$\text{s.t. } \mathbf{A}_k \cdot \mathbf{x}_k \leq \mathbf{z}_k \quad (2)$$

$$\mathbf{x}_k \geq 0 \quad (3)$$

- $\mathbf{g}_k$ is the n-vector of gross margins
- $\mathbf{x}_k$ is the n-vector of producing activities
- $\mathbf{A}_k$ is a $m \times n$-matrix, describing the feasible production set

Key modelling features

- **CAP measures:** mandatory set aside, milk quotas, compensatory payments, intervention prices, etc.
- **Area constraints:** total area constraint, maximal area shares, balance between crops, between cereals and oilseeds, etc.
- **Livestock demography (cattle):** Demographic equilibrium between age classes, stable places constraints.
- **Livestock feeding:** Protein and energy requirements by animal categories, maximum ingested matter
- **Manure management:** Constant nitrogen excretion rates by animal categories, fixed shares of each management system as in the NCs to the UNFCCC
- **Fertilizer use:** Total fertilizer expenditures from FADN, split by crop for each farm type, assumption on a composite fertilizer price by crop and by country. Fixed per-hectare N input by crop and by farm-type.

Emission accounting

- Based on the IPCC *Good Practice Guidelines* emission factors linked to the relevant optimal levels of producing activities at the farm-type level
- Emission coverage consistent with the 2003 NC to the UNFCCC
- Country-differentiated emission factors if available in the NC to the UNFCCC; default IPCC emission factors otherwise

$$e_k = \sum_{l=1}^{L} \mathbf{f}_{k,l} \cdot \mathbf{x}_k$$

- e_k: Total emissions (in tCO_2eq) for farm-type k.
- $l = 1, \ldots, L$ sources
- $\mathbf{f}_{k,l}$: n-vector of emission factors for source l and farm-type k.

Emission coverage

Emission sources	Activity data	Linked to
N_2O Agricultural soils		
Direct Emissions		
Use of synth. fertilizers	N fert. application	Crop area
Manure application	N excr. by animals	Animal numbers
Biological N fixation	Prod. of N-fixing crops	N-fixing crop area
Crop residues	Reutil. of crop residues	Crop area
Animal production	N excr. by graz. anim.	Animal numbers
Indirect Emissions		
Atmospheric deposition	Total N application	Crop area and animal numbers
Leaching and run-off	Total N application	Crop area and animal numbers
N_2O Manure manag.	Animal numbers	Animal numbers
CH_4 Manure manag.$^{(*)}$	Feed energy intake	Animal feeding and animal numbers
CH_4 Ent. fermentation$^{(*)}$	Feed energy intake	Animal feeding and animal numbers
CH_4 Rice cultivation	Rice area	Rice area

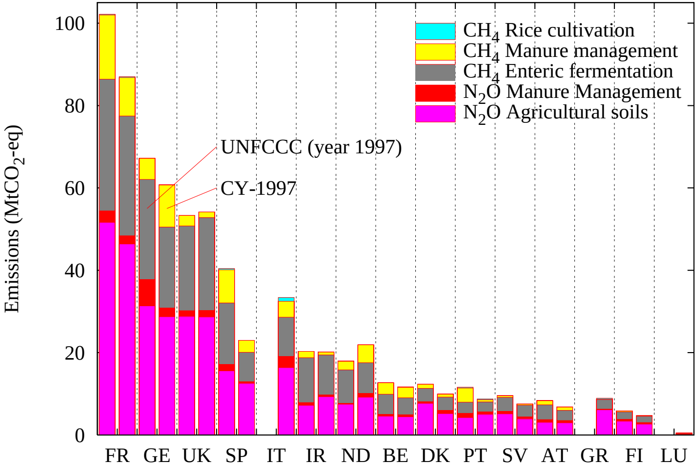
$^{(*)}$ Further disaggregated into: Dairy cattle, non-dairy cattle, sheep, goats, swine, and poultry.

Simulation of marginal abatement cost curves

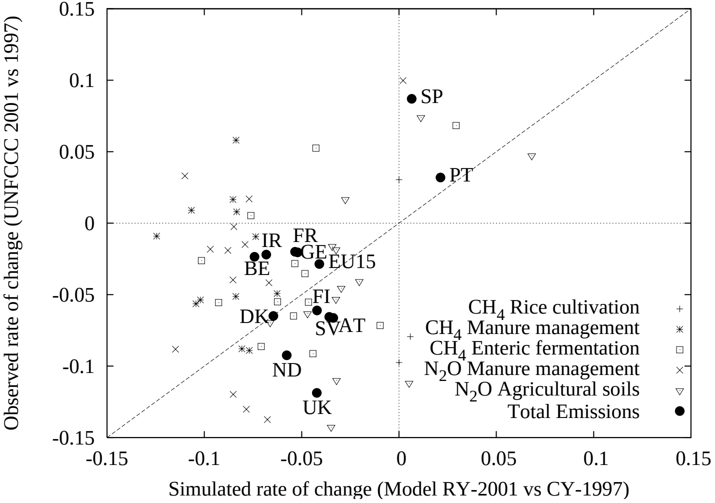
- Two baseline runs:
  - CY-1997: Calibration year
  - RY-2001: Reference year, includes the changes in CAP policy between 1997 and 2001 ("Agenda 2000"), same dataset otherwise
- An emission tax is added to the objective function: from 0 to 100 EUR/tCO_2 For each farm-type k:

$$
\begin{aligned}
\max_{\mathbf{x}_k} \pi_k(\mathbf{x}_k) &= \mathbf{g}_k \cdot \mathbf{x}_k - t.e_k && (4)\\
\text{s.t. } \mathbf{A}_k \cdot \mathbf{x}_k &\leq \mathbf{z}_k && (5)\\
\mathbf{x}_k &\geq 0 && (6)\\
e_k &= \sum_{l=1}^{L} \mathbf{f}_{k,l} \cdot \mathbf{x}_k && (7)
\end{aligned}
$$

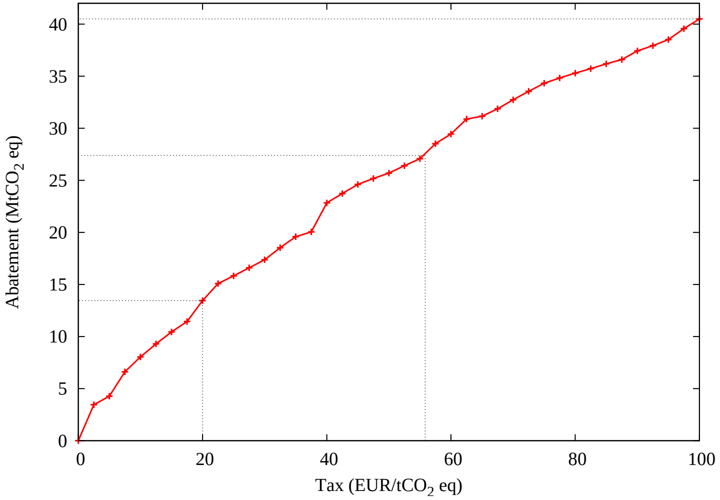
Observed vs modelled N_2O and CH_4 emissions



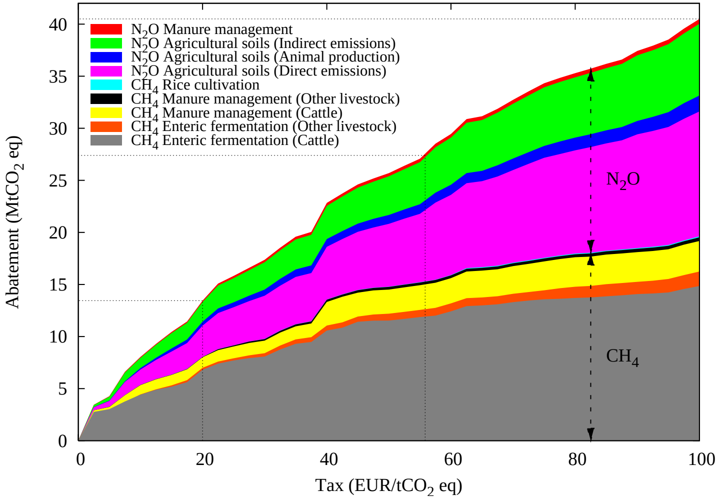
Change in emissions between 1997 and 2001



Abatement supply (EU-15)



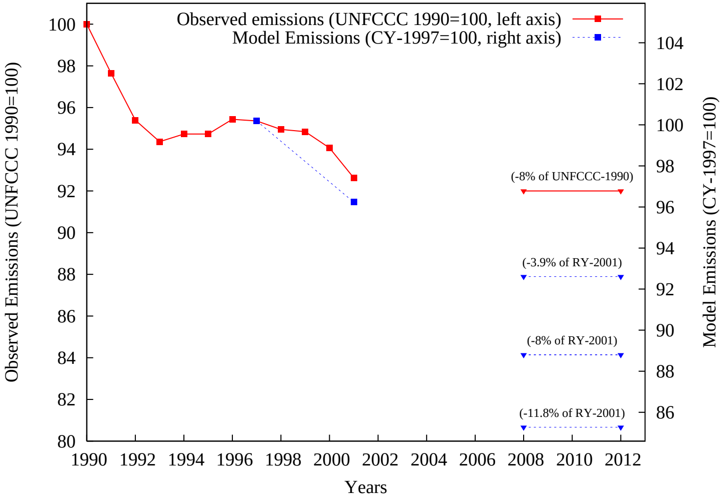
Abatement supply (EU-15)



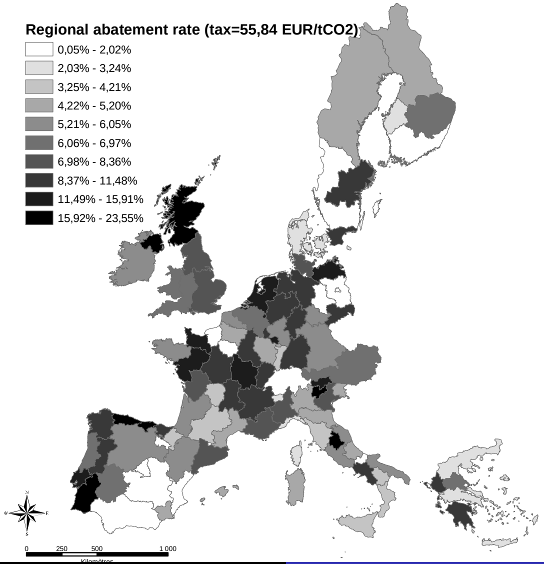
Marginal abatement costs: Discussion

- Total abatement depends on emission factors. Uncertainty and heterogeneity of IPCC emission factors.
- Only methane and nitrous oxide emissions (no carbon sequestration).
- Abatement results solely from changes in crop area allocation, animal feeding, and animal numbers:
  - No adoption of alternative management practices.
  - No "cleaning" technology.
  - Constant nitrogen application by crop and farm-type.
- No price impact (price-taker assumption).
- No structural changes (constant farmers population).
- No change in the macroeconomic and policy environment.

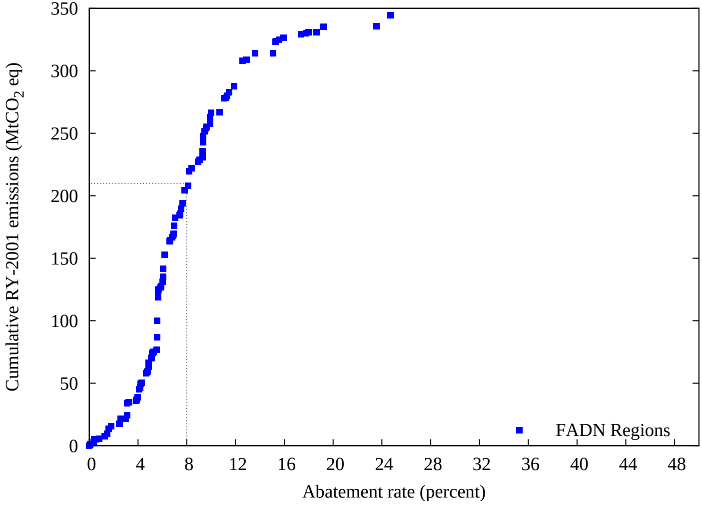
Implied abatement vs Kyoto target



Regional abatement rates



Distribution of regional abatement rates



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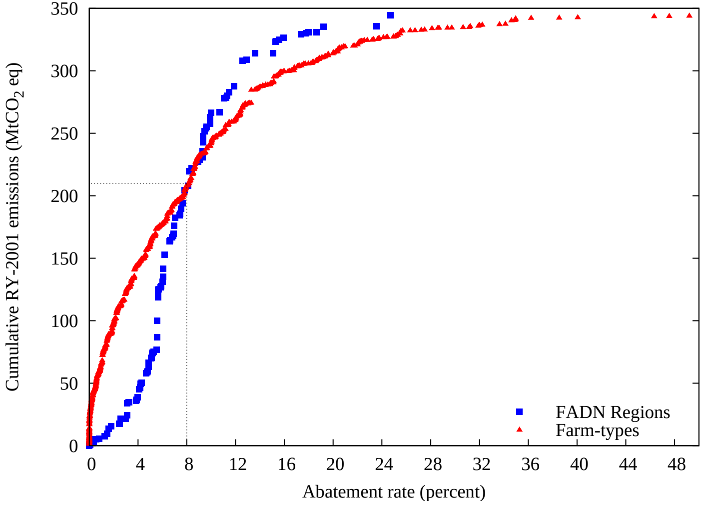
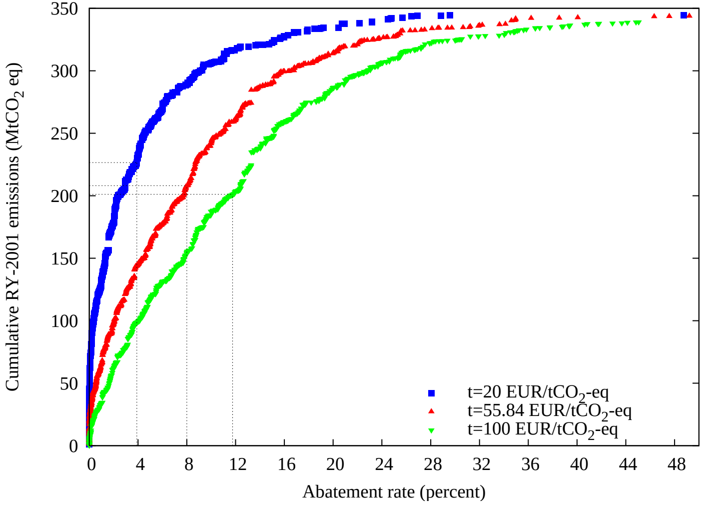


Distribution of abatement rates (cont'd)



Cost-saving of an emission tax relative to a uniform abatement rate target

Abatement target	Total abatement	Marginal abatement cost		Cost-saving ratio
		Emission tax	Uniform quotas	
γ		t	$\bar{\lambda}(\gamma)$	$\bar{\lambda}(\gamma)/t(\gamma)$
(%)	($MtCO_2eq$)	(EUR/tCO_2)	(EUR/tCO_2)	
4%	13.78	20.51	73.64	3.6
8%	27.56	55.84	122.66	2.2
12%	41.35	$>$100.00	169.62	$<$1.7

Concluding remarks

- The EEA (2004) projects that total EU abatement will fall short of the Kyoto target by 34 $MtCO_2$ with existing policies and measures
  ⇒ Estimated abatement costs indicate that agriculture could play an important role in bridging this gap.
- Heterogeneity of abatement costs is important both between and within regions
- Agricultural policies have a long history of uniform instruments
  ⇒ Given the heterogeneity of abatement costs, this would lead to significantly higher overall abatement costs
- Cost-effective vs efficient policy instruments: Uncertainty about climate change damage.
- Price impacts of mitigation policies?
- Carbon sequestration (soil, forestry) vs GHG abatement?