Non-Point Source Pollution and spatial dimensions of environmental policies

Environmental Economics and Policy Instruments

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Non-point source pollution: pollution from diffuse sources

1. Introduction: EPA's water quality voluntary trading program
2. A model with pollution diffusion across space
3. Examples
4. Optimum and laissez-faire
5. Regulations
   - emission standards
   - emission fees
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   - Ambient tax
6. An experiment of ambient tax regulations

Getting Paid for Stewardship: An Agricultural Community Water Quality Trading Guide

Conservation Technology Information Center

July 2006

Water Quality Trading in Agriculture

What is trading?

Water quality trading is a market-based approach to improve water quality being used in some **watersheds**. It is a tool that connects industrial and municipal facilities subject to wastewater permit requirements with agricultural producers to economically achieve water quality improvements. These permitted facilities are referred to as **point sources** and, in this context, agricultural producers are referred to as **nonpoint sources**. Through water quality trading, a point source, such as a wastewater treatment plant, facing relatively high costs to remove excessive amounts of substances, such as nitrogen and phosphorus will compensate another party—either another point source or a nonpoint source, such as a farm or ranch—for less costly, yet equivalent, pollutant reduction. The trading partners enter into a contractual trading agreement, where both will benefit financially, and water quality will be improved with a lower investment. A water quality trading market exists only when point and nonpoint sources in a watershed have very different opportunities and costs to reduce their respective pollutant contributions, thereby creating a market for less-expensive approaches to improving water quality. Agricultural conservation practices are one such approach.

Figure 1. Water Quality Trading

Many pilot projects have explored trading activities and several states have established, or are actively considering, trading programs. For more information on the current status of trading across the country, go to EPA's water quality trading web site at *www.epa.gov/owow/watershed.trading.htm*.

Pollutant Reduction Certificate
EXAMPLE

VALID FOR POLLUTANT REDUCTION ACTIVITY FOR MONTH(S): ____________________ YEAR: _________

NAME OF FACILITY GENERATING CREDITS:

CONTACT NAME:

ADDRESS:

PHONE NUMBER:

BEST MANAGEMENT PRACTICE (BMP) IDENTIFIER:
– Type of BMP:

– Location of BMP:

VERIFICATION METHOD:

VERIFICATION FREQUENCY:

VERIFICATION RESULTS (POUNDS OF POLLUTANT REMOVED*) (A):

*Not to include pollutant required by, or resulting from, trading baseline requirement

TRADE RATIO (B):

______________ = ____________ x _____________ x _____________

Trade Ratio | Ratio #1 (if applicable) | Ratio #2 (if applicable) | Ratio #3 (if applicable)

AMOUNT OF MARKETABLE CREDITS:

Total Reduction Amount in Pounds Removed x Trade Ratio (A x B) = __________

<u>CERTIFICATION:</u>

I certify that the above information is accurate and truthful to the best of my knowledge and is in accord with the state's trading program.

Signature of Authorized Representative of Buyer:

____

Signature of Authorized Representative of Seller:

____

negotiate directly with permitted facilities wanting to buy credits, only with the central exchange. The central exchange will likely have its own eligibility requirements and enter into separate agreements with each seller and buyer. The central exchange might also charge a service fee to help defray administrative and transaction costs.

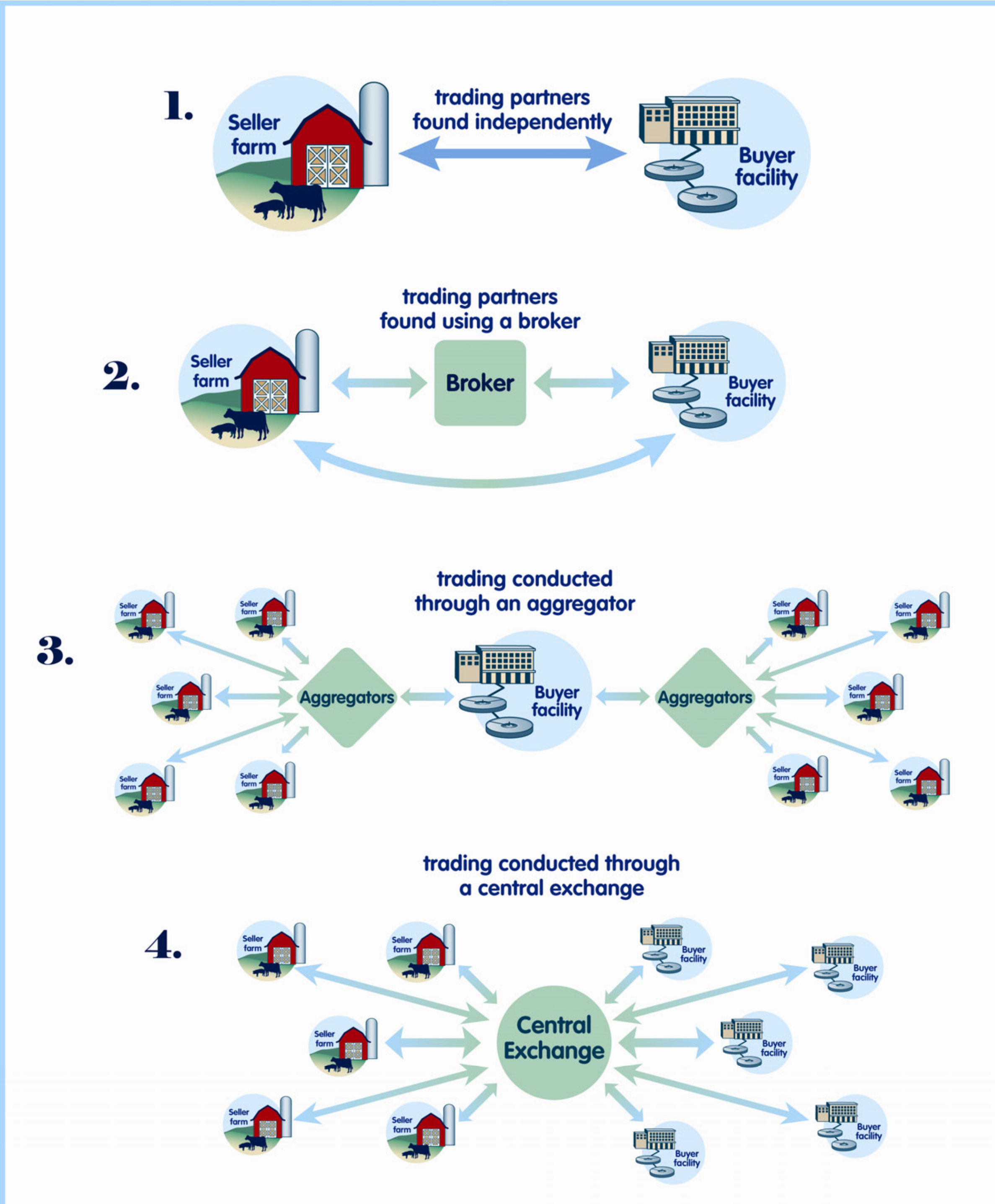


Figure 3. Finding a trading partner

Model of pollution with space 1/2

- Based on Montgomery (1972)
- Agents (firms, consumers, cities, countries) $i \in N \equiv \{1, ..., n\}$
- S_i: set of agents who pollute i (sources of pollution at i)
- R_i: set of agents polluted by i (receptors of i's pollution)

Model of pollution with space 2/2

- e_i: emissions by i Emission (saving) cost $C_i(e_i)$
- $C_i(e_i) > 0$, $C_i'(e_i) < 0$, $C_i''(e_i) > 0$
- α_{ij} : transfer coefficient from i to j
  Marginal impact of i's emissions on pollution in j
- Pollution at j

$$P_j = \sum_{i \in S_j} \alpha_{ij} e_i$$

- Damage at j: $d_j(P_j) > 0$, $d_j'(P_j) > 0$, $d_j''(P_j) > 0$ for every $P_j > 0$
- Some agents can only be polluter only, i.e. $d_i = 0$ or victim only ($C_i = 0$ and $e_i = 0$).

S_i and R_i

$$S_i = \{j \in N | \alpha_{ji} > 0\}$$

$$R_i = \{j \in N | \alpha_{ij} > 0\}$$

River pollution

- Agents (cities, countries, firms) ordered by their position on the river:
  $i < j$ means i upstream j
- e_i: waste water emitted by i
- P_i: water pollution (BOD) at i
- $S_i = \{1, ..., i-1\}$ or $S_i = \{1, ..., i\}$ set of predecessors of i
- $R_j = \{i+1, ..., n\}$ or $R_j = \{i, ..., n\}$ set of followers of i
- α_{ij} related to distance and absorption capacity (e.g. marsh, tributaries)
- If only one receptor, i.e lake downstream then $d_j = 0$ for $j < n$ and $c_n = 0$

Greenhouse gas emissions

- Countries or firms/consumers $i = 1, ..., n$
- e_i: GES emissions
- $S_i = R_i = N$ for countries
- $\alpha_{ii} = \alpha_{ij} = \alpha_i$: for the same greenhouse component (CO2, CH4 -methane, N2O -nitrous oxides,...)
- P_j: greenhouse concentration (in CO2 equivalent) or impact (e.g. temperature increase)
- 1 unit CH4 impacts 23 times than CO2, N2O is 296 times

SO2 emissions

- Countries $i = 1, ..., n$
- Sulfur dioxide (SO2) emissions e_i
- S_i: set of countries polluting i
- α_{ij} is related to SO2 "transportation" among countries
  e.g. among the SO2 emissions from Belgium, 19.4% ended up in Belgium, 13.3% in Germany, 9% in France, 4.8% in Netherland in 1992 according to Mäler and De Zeeuw (1998)
- P_i: sulfur concentration at i

Laissez-faire

Let $S_i^0 = S_i \backslash \{i\}$
$\mathbf{e}^e \equiv (e_i^e)_{i=1,\dots,n}$ solution to for every $i \in N$:

$$\min_{e_i} C_i(e_i) + d_i \left(\alpha_{ii} e_i + \sum_{j \in S_i^0} \alpha_{ji} e_j^e \right)$$

First-order conditions:

$$-C_i'(e_i^e) = \alpha_{ii} d_i'(P_i^e)$$

for every $i \in N$ with

$$P_j^e = \sum_{k \in S_j} \alpha_{kj} e_k^e$$

If $d_i = 0$ or $\alpha_{ii} = 0$ then $e_i^e = \hat{e}_i$ with $C_i(\hat{e}_i) = 0$

Optimum

$\mathbf{e}^* \equiv (e_i^*)_{i=1,\dots,n}$ solution to:

$$\min_{\mathbf{e}} \sum_{i \in N} \left[C_i(e_i) + d_i \left(\sum_{j \in S_i} \alpha_{ji} e_j \right) \right]$$

First-order conditions:

$$-C_i'(e_i^*) = \sum_{j \in R_i} \alpha_{ij} d_j'(P_j^*)$$

for every $i \in N$, with

$$P_j^* = \sum_{k \in S_j} \alpha_{kj} e_k^*$$

Marginal abatement (or emission saving) cost equals to marginal damage accounting for the transfer coefficient

1 polluter $n - 1$ receptor

- Firm 1 pollutes $j = 2, ..., n$ victims
- α_{ij}: marginal impact of i's emissions on pollution concentration P_j at j
- Efficiency:

$$-C_1'(e_1^*) = \sum_{j=2}^{n} \alpha_{ij} d_j'(P_j^*)$$

- Modified public bad solution

$n-1$ polluters one receptor

- Firms $i = 1, ..., n-1$ pollute agent n
- α_{in}: marginal impact of i's emissions on pollution concentration P_n
- Efficiency:

$$\frac{-C_i'(e_i^*)}{\alpha_{in}} = \frac{-C_j'(e_j^*)}{\alpha_{jn}} = d_n'(P_n^*)$$

- Modified equimarginal principle:
  Equal marginal abatement costs per unit of pollution

International river pollution

- Countries $i = 1, ..., n$ labeled from upstream to downstream
- Let $\alpha_{ij} = 1$ for $i \leq j$ ($\alpha_{ij} = 0$ for $i > j$), $d_i > 0$ and $C_i > 0$ for every $i \in N$
- Efficiency:

$$-C_i'(e_i^*) = \sum_{j=i}^{n} d_j'(P_j^*)$$

- For $i < j$,

$$-C_i'(e_i^*) > -C_j'(e_j^*)$$

- If $C_i = C$ for every i then $e_i^* < e_j^*$

Emission cap

- As before a uniform emission cap fails to implements the first-best and now neither the efficient pollution levels P_j^* for every receptor j
- Efficiency requires individual emissions caps $\bar{e}_i$ but difficult to implement for non-point source pollution (fertilizers, pesticides,...)
- Often local pollution caps $\bar{P}_j$ with command-and-control regulations
- How divide $\bar{P}_j$ among polluters in S_i? Example of farmers' associations

Emission fees

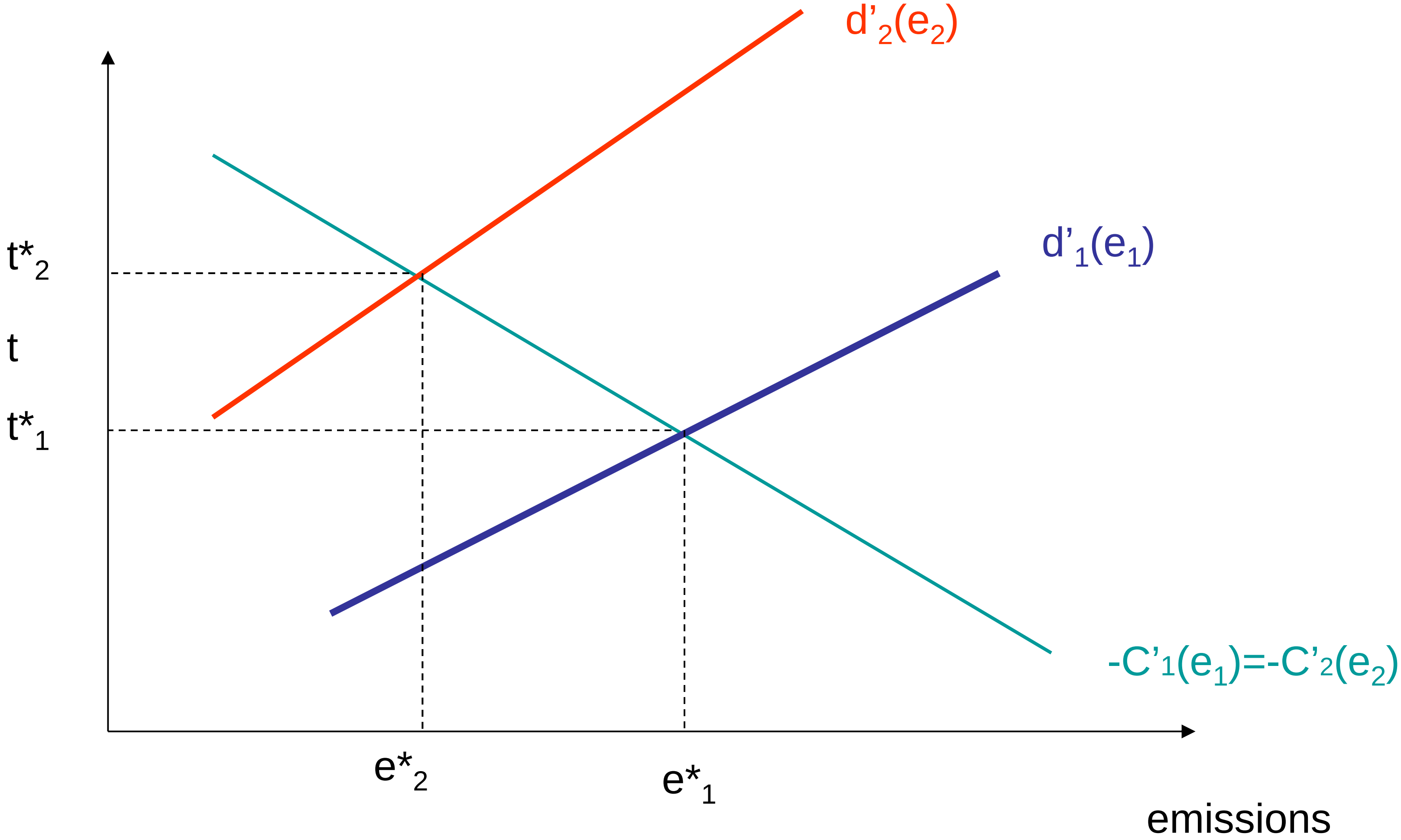
- First-best implemented with tax on emissions

$$t_i^* = \sum_{j \in R_i} \alpha_{ij} d_j'(P_j^*)$$

- Need information on α_{ij} and e_i
- Difficult to compute and implement in practice
- Ambient tax t_j per unit of pollution P_j applied to agents in S_j, e.g. marginal damage at the first-best $t_j = d_j'(P_j^*)$
- How to assign the tax paid $t_j P_j$ among S_j?
- Problem of free-riding within S_j
- Loss of welfare with uniform tax t

2 x (1 source – 1 receptor) with same benefits but different damages

Firm i pollutes at location i for i=1,2



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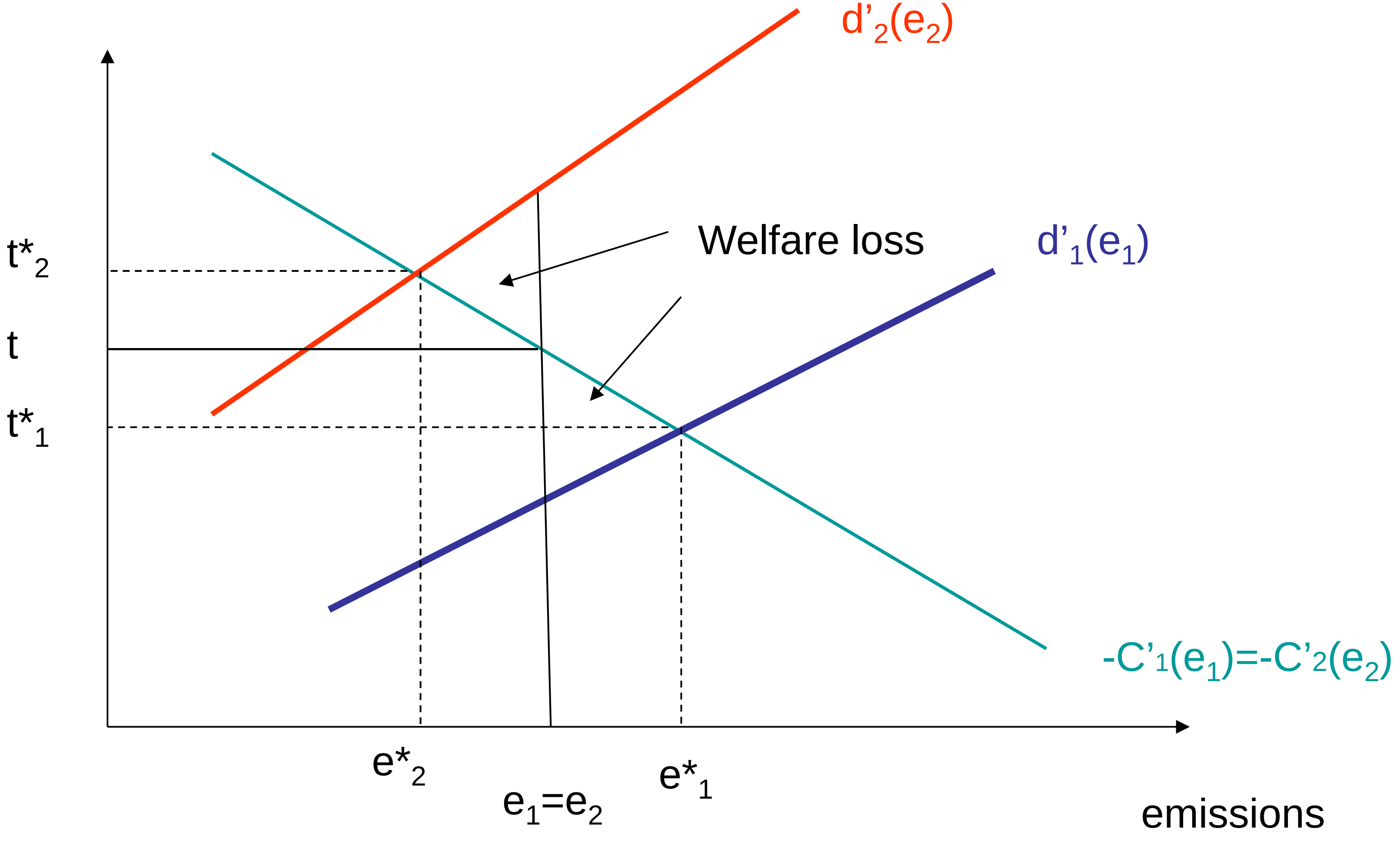


Cap-and-trade 1/3

- Market on ambient permits at each receptor j
- Divide ambient pollution into emissions caps
- l_j^i: i's pollution rights in j
- L_j^i: i's initial endowment
- p_j: price of pollution rights in j
- In terms of emissions from i at j: $a_{ij}e_i \leq l_j^i$

Cap-and-trade 2/3

Each agent i solves

$$\min_{e_i,(l_j^i)_{j\in R_i}} C_i(e_i) + \sum_{j\in R_i} p_j(l_j^i - L_j^i)$$

subject to $e_i \leq \frac{l_j^i}{\alpha_{ij}}$ for every $j \in R_i$,
First-order conditions with binding constraints:

$$\frac{-C'(e_i)}{\alpha_{ij}} = p_j$$

for every $i \in S_j$ for every i and market clearing conditions for every j

$$\sum_{l\in S_j} l_j^l = \sum_{l\in S_j} L_j^l$$

Cap-and-trade 3/3

- Equilibrium price equals to marginal damage at first-best if $\sum_{l \in S_j} L_j^l = P_j^*$
- Problem of market thinness in each location j
- Link α_{ij} between e_i and P_j to be evaluated
- In practice:
  - Emission caps and pollution offset in urban areas
  - Water discharge caps and "trading" (among farmers or with water treatment plant) in rural areas
  - Market with air pollution and emission norms on "hot spots"

Ambient tax

- Segerson (JEEM 1988)
- Cut-off on ambient pollution $\tilde{P}$
- Fee or subsidy scheme to be paid by each potential polluter depending on its impact a_{ij}:

$$T_i(P) = \begin{cases} t_i(P - \tilde{P}) + k_i & \text{if} \quad P > \tilde{P} \\ t_i(P - \tilde{P}) & \text{if} \quad P \leq \tilde{P} \end{cases}$$

- Implements first-best when t_i and k_i properly computed
- Problem of information, discriminatory taxation and budget-balance

Experiment of ambient taxes 1/2

- Cochard, Willinger and Xepapadeas, ERE 2005
- Contribution to a public bad game
- Payoffs:

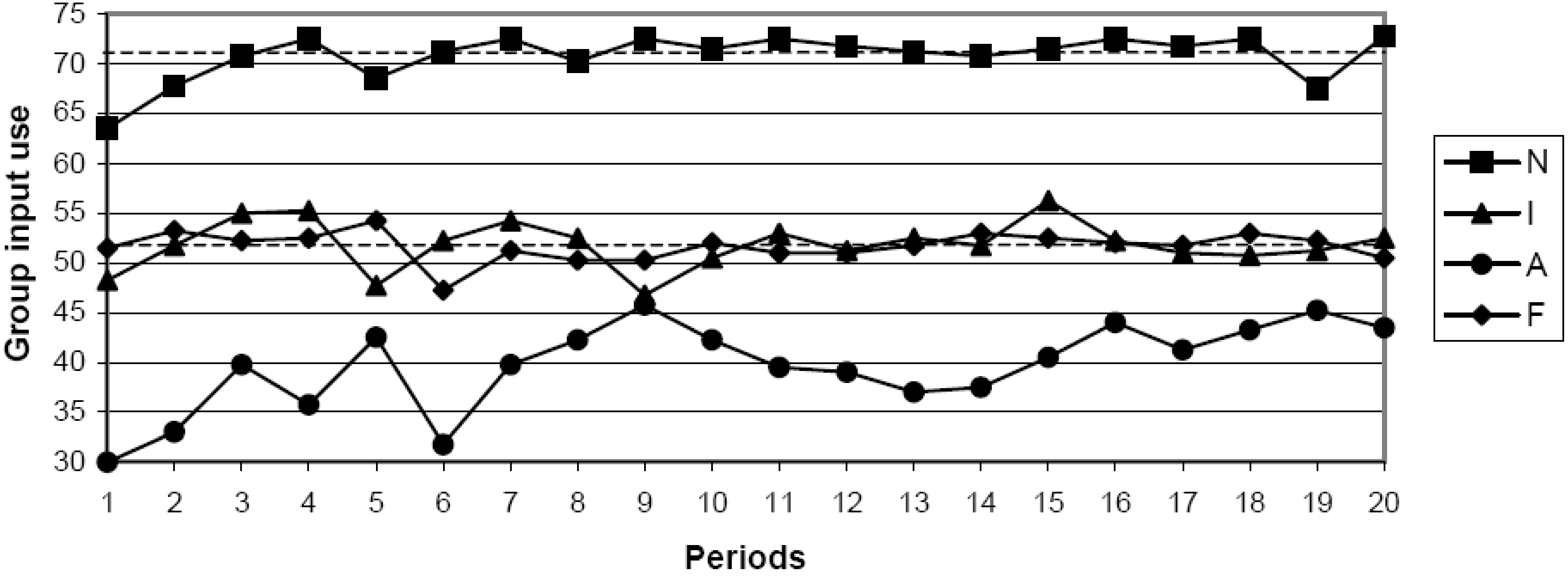
$$f(x_i) - \delta \sum_i x_i$$

  with $f(x)$ quadratic
- Groups of 4 subjects played a treatment/game
- Dominant/Nash strategy $x^e = 18$; total pollution $18 \times 4 = 72$
- Efficient strategy $x^* = 13$
- efficient pollution cut-off $nx^* = 13 \times 4 = 52$

Experiment of ambient taxes 2/2

Four treatments:

- no regulation N
- tax per unit of pollution I
- ambient tax and subsidy per unit of emissions with efficient pollution level as cut-off A
- group fine if above cut-off F


75
70
65
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Group input use
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Periods
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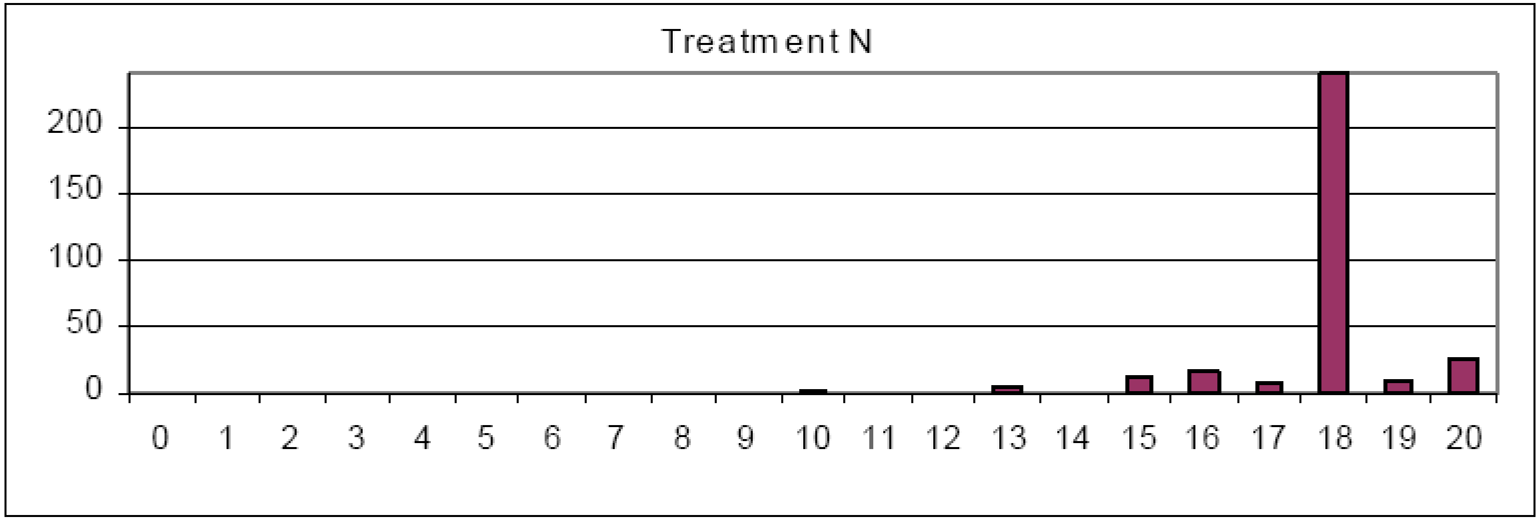
Treatment N
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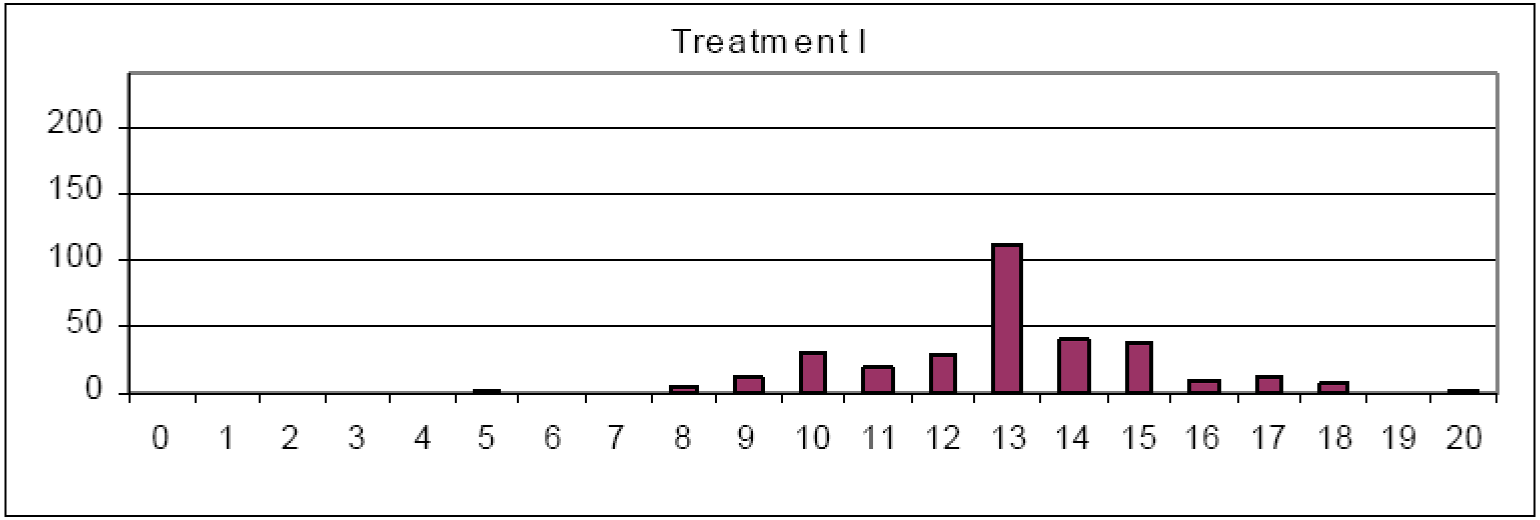
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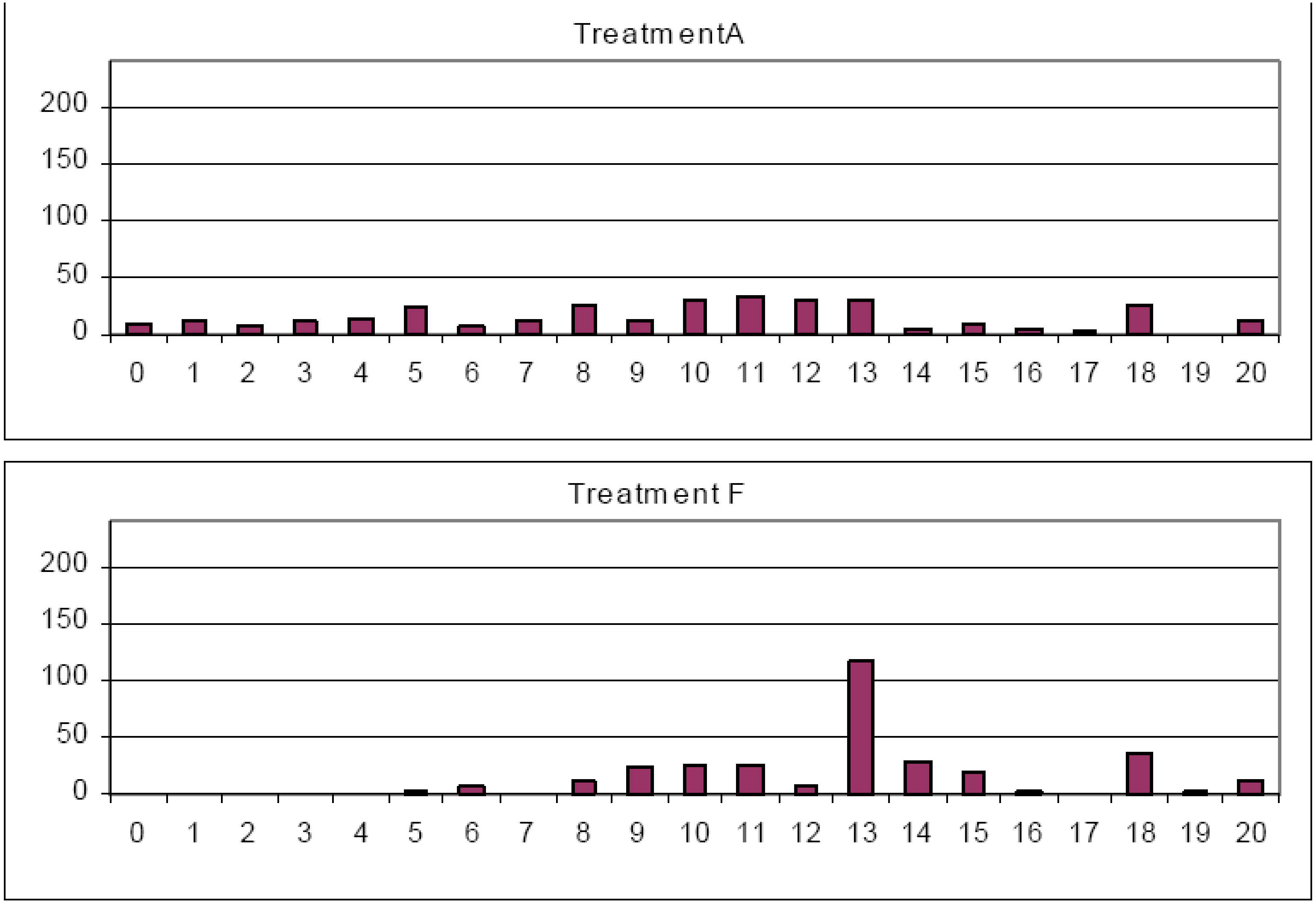

Note: There is a total of 320 observations per treatment (16 subjects make 20 input decisions)

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