

# M2R APE Environmental Economics

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# Course structure

The course combines the theory behind the design of environmental regulation with the current research landscape that explores how regulation works in practice.

## 3 instructors

- Lectures 1-6: Mireille Chiroleu-Assouline
- Lectures 7-9: Hélène Ollivier
- Lectures 10-12: Matthew Gordon

# Course evaluation

- The grading breakdown for the course is:
  - 50% for the part related to Mireille Chiroleu-Assouline's classes
  - 50% for the part related to Matthew Gordon and H el ene Ollivier's classes
- The grading associated with this part of the course is decomposed into:
  - 20% on the best grade from two short in-class written tests (at the start of Lecture 3 and 6)
  - 80% on the first part of the final exam, with half of the grade on a short essay and the other half on an analytical problem

# Outline of this part of the course

- ① Environmental regulation without uncertainty
- ② Environmental regulation in an uncertain world
- ③ Environmental regulation under ex ante asymmetric information
- ④ Environmental risk regulation under ex post asymmetric information

# References

- Tietenberg T., Lewis L. [2023], *Environmental and Natural Resource Economics*, 12th Edition, Roulledge.
- Kolstad C. [2010], *Environmental Economics*, 2nd Edition, Oxford University Press.
- Hanley N., Shogren J.F., White B. [1997], *Environmental Economics in Theory and Practice*, Oxford University Press, Oxford.
- Perman R., Ma Y., Common M., Maddison D., McGilvray J., [2011], *Natural Resources and Environmental Economics*, 4th Edition, Addison-Wesley.
- Pearce D.W. et Turner R.K. [1990], *Economics of Natural Resources and the Environment*, Harvester Wheatsheaf.

# Chapter 1 : Environmental regulation without uncertainty

- 1 Externalities and theorems of welfare economics
- 2 Optimal pollution and internalization of the externalities
- 3 Comparison between instruments (efficiency/dynamic efficiency/distributive effects)
- 4 Focus on the distributive effects of carbon pricing

# 1. Externalities and theorems of welfare economics

## Theorem

*When the market system is complete and **when there is no externality**, if the utility functions are strictly increasing, **any competitive equilibrium is Pareto optimal.***

## Theorem

*If the utility functions are continuous, increasing and quasi-concave, and if the consumption sets and the production sets are closed and convex, then **any Pareto optimum can be decentralized into a competitive equilibrium.***

# 1. Externalities and theorems of welfare economics

## Definition

*Externality = Effect imposed, because of the choices of an agent on the welfare (utility or profit) of another agent, without any market transaction between them.*

### Market Failures

- Externalities
- Incomplete markets
- Imperfect competition
- Transaction costs
- Information asymmetry

*As soon as one of these market failures exists, the decentralized equilibrium does not yield the Pareto optimum.*

# 1. Externalities and theorems of welfare economics

## Externalities

- positive (amenities)  $\neq$  negative (pollutions)
- bilateral  $\neq$  multilateral
- rival or private (waste)  $\neq$  non rival (greenhouse gas)
- static (air pollution, ozone)  $\neq$  dynamic (climate change)
- transferable (waste)
- non-point source (water pollution)
- global (climate change)

## 2. Optimal pollution and internalization of the externalities

### Profit of the polluting firm $i$

$e_i$  : polluting emissions

$$\pi(Q_i, e_i) \text{ or } \pi(e_i)$$

which is a reduced form for a more complete model:

- the profit increases with output and would decrease if, for a given level of output, the firm chose to emit less (equivalent to say that profit increases with emissions)
- this reduced form enables to encompass two alternative ways for reducing emissions:
  - to reduce output
  - to use a cleaner technology in order to emit less with unchanged output

## 2. Optimal pollution and internalization of the externalities

Polluting firm  $i$  with pollution  $e_i$

- profit function:  $\pi^i(e_i)$
- marginal profit of pollution  $\pi_m^i(e_i)$  denoted  $\pi_m^i$  positive and decreasing, leading to decentralized emissions  $e_i^D$
- the abatement cost is defined as the cost of reducing emissions

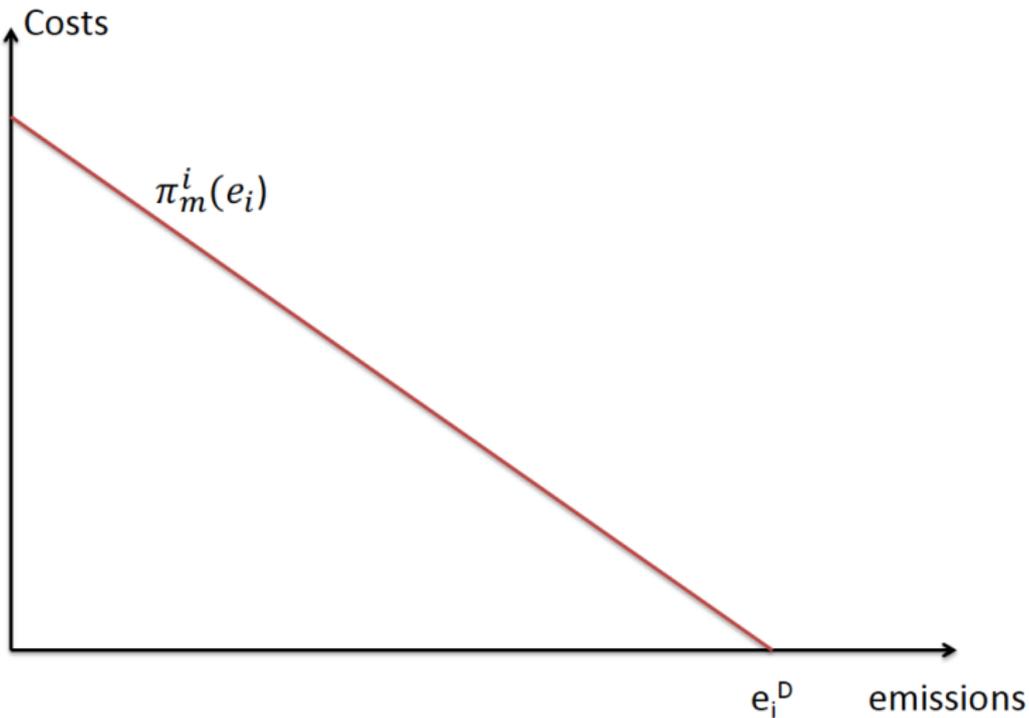
$\implies$  for abatement  $a_i = e_i^D - e_i$ ,

the marginal abatement cost  $MAC^i(a_i)$  is the foregone marginal profit

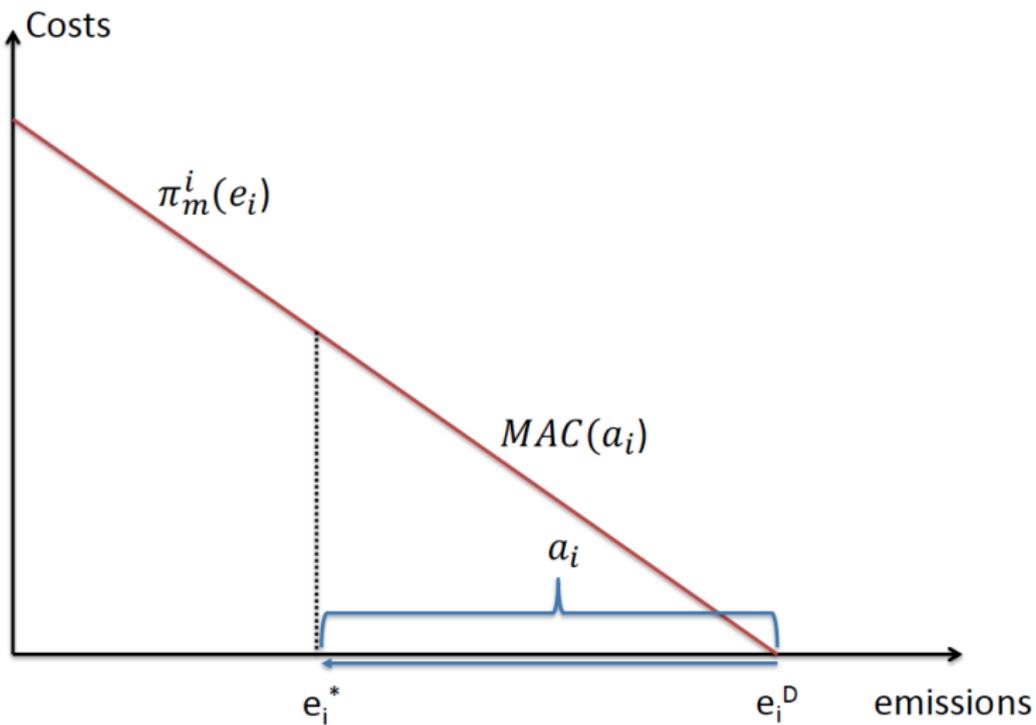
$$\Leftrightarrow MAC^i(a_i) = MAC^i(e_i^D - e_i) = \pi_m^i(e_i)$$

$$\implies \frac{\partial MAC^i(a_i)}{\partial a_i} = -\frac{\partial \pi_m^i(e_i)}{\partial e_i} > 0$$

# Marginal profit of emissions



# Marginal abatement cost



## 2. Optimal pollution and internalization of the externalities

Total damage  $D(E)$  endured by the polluted = external cost (or disutility) of the aggregate pollution  $E$

with  $E = \sum_{i=1}^I e_i$

Usual assumptions:

$$\left\{ \begin{array}{ll} D(E) = 0 & \text{if } E < \underline{E} \\ D(E) > 0 & \text{if } E > \underline{E} \\ D_m = \frac{\partial D}{\partial E} > 0 & \frac{\partial^2 D}{\partial E^2} > 0 \end{array} \right.$$

where  $\underline{E} \geq 0$  : threshold of natural elimination of pollutants

# Optimal pollution and internalization of the externalities

Pareto optimum  $\equiv$  social welfare maximization (or total cost minimization)

**Social cost = external cost**

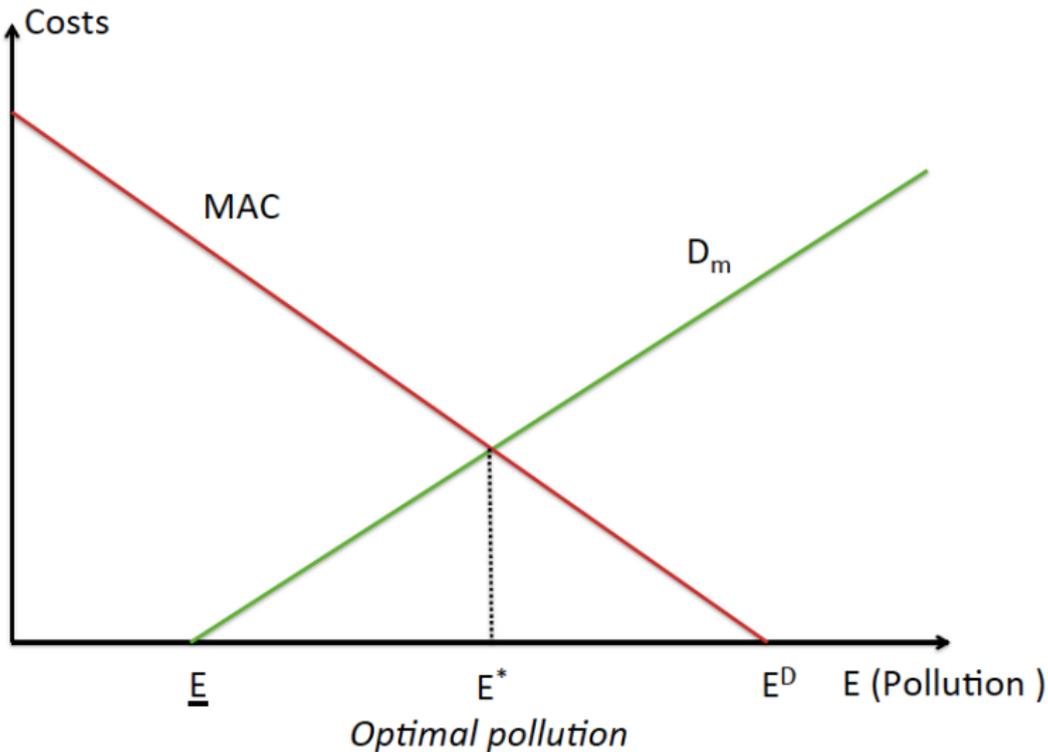
$\Leftrightarrow$  Benefit of abatement  $B(A) = -D(E^D - E)$  avoided damage

$$\begin{aligned} \max W &= \sum_{i=1}^I \pi^i(e_i) - D(E) && \Leftrightarrow \min C = \sum_{i=1}^I C^i(e_i) + D(E) \\ &&& \Leftrightarrow \max W = B(A) - \sum_{i=1}^I AC^i(a_i) \end{aligned}$$

$$E = \sum_{i=1}^I e_i$$

$$\text{FOC : } \pi_m^i(e_i^*) = MAC^i(e_i^D - e_i^*) = D_m(E^*) \quad \forall i$$

# Optimal pollution and internalization of the externalities



# Optimal pollution and internalization of the externalities

## *Cost-benefit Analysis (CBA) at the society level*

- External cost = damage due to polluting emissions
  - Any additional unit of pollution causes an additional damage = **marginal damage (increasing with pollution)**
  - $\iff$  Any additional unit of abatement causes an additional benefit (avoided damage) = marginal benefit
- Any pollution abatement is costly
  - **Marginal abatement cost**, positive and increasing with the abatement, thus decreasing with polluting emissions
  - Without regulation, the polluter minimizes this private cost (the marginal abatement cost is null while the marginal damage is high)
- As long as the marginal abatement cost is less than the marginal damage, society has incentive to reduce the level of pollution  $\rightsquigarrow$   
Objective : **internalize externalities**
- Climate change case: uncertainty, cumulative and irreversible effects  
 $\rightsquigarrow$  *cost-efficiency analysis* (for a given objective)

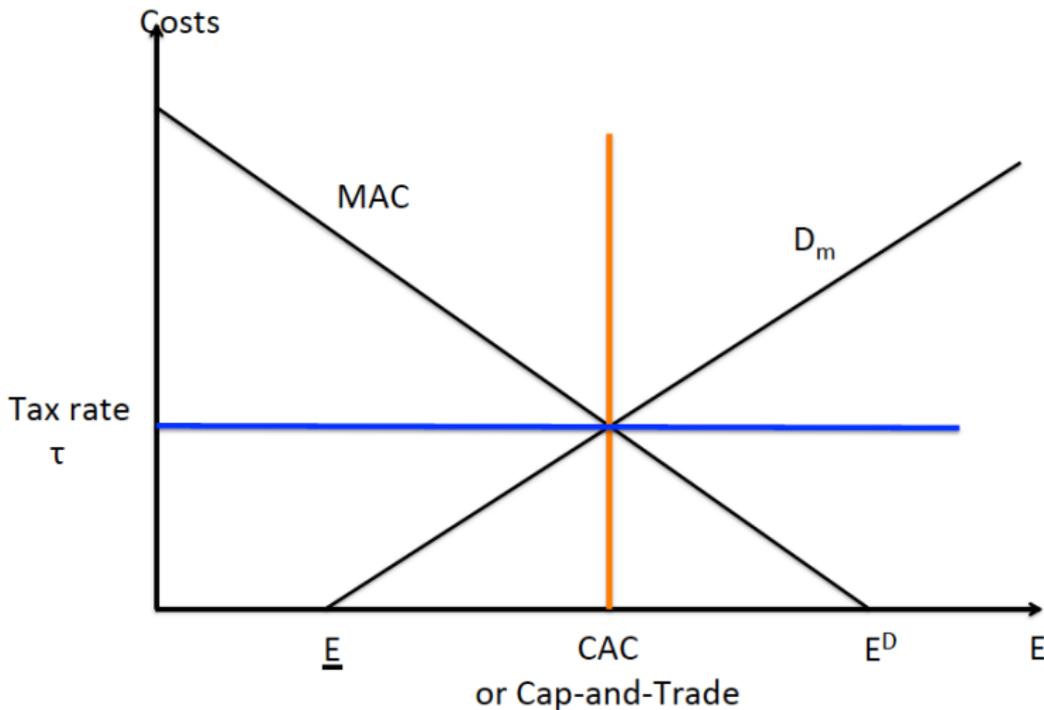
# 2. Optimal pollution and internalization of the externalities

## Instruments aiming at internalization:

- Command and control (CAC):
  - Standards
- Market-based instruments (MBI):
  - Pigovian tax: **price instrument**
  - Abatement subsidy
  - Cap-and-trade (emission permits): **quantity instrument**

# 2. Optimal pollution and internalization of the externalities

Instruments aiming at addressing the externalities:



### Compliance carbon pricing instruments around the world, 2025

Map shows jurisdictions with carbon taxes or emissions trading systems implemented, under development or under consideration, subject to any filters applied in the table below the map. The year can be adjusted using the slider below the map.

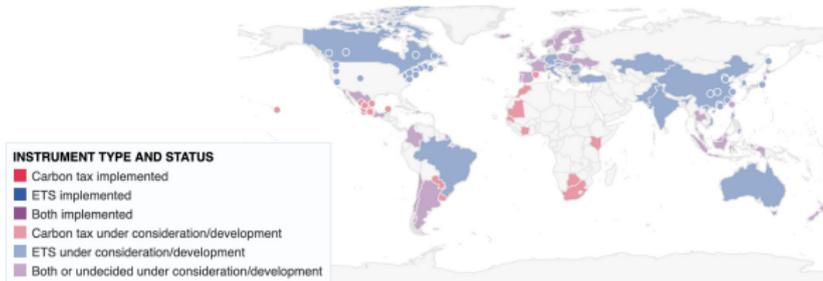


Figure: Carbon Pricing Map (World Bank, 2025)

<https://carbonpricingdashboard.worldbank.org/>

Carbon pricing instruments are considered: "Implemented" once they have been formally adopted through legislation and compliance obligations are in force and enforced; "Under development" if the government is actively working towards the implementation of a specific carbon pricing instrument, a mandate may have been established, but regulated entities do not yet face compliance obligations, and this has been formally confirmed by official government sources; or "Under consideration" if the government has announced its intention to work towards the implementation of a carbon pricing instrument and this has been formally confirmed by official government sources.

# Carbon pricing implementation timeline



- Why are market-based instruments widely adopted?
- How should they be designed?



Only 20% of covered emissions are priced in line with the Stern-Stiglitz Commission's recommendations, which in 2017 estimated that full incentive effects require prices between USD 40-80/tCO<sub>2</sub>e by 2020, and USD 50-100/tCO<sub>2</sub>e by 2030.

Around 74% of covered emissions are priced below USD 20/tCO<sub>2</sub>e.

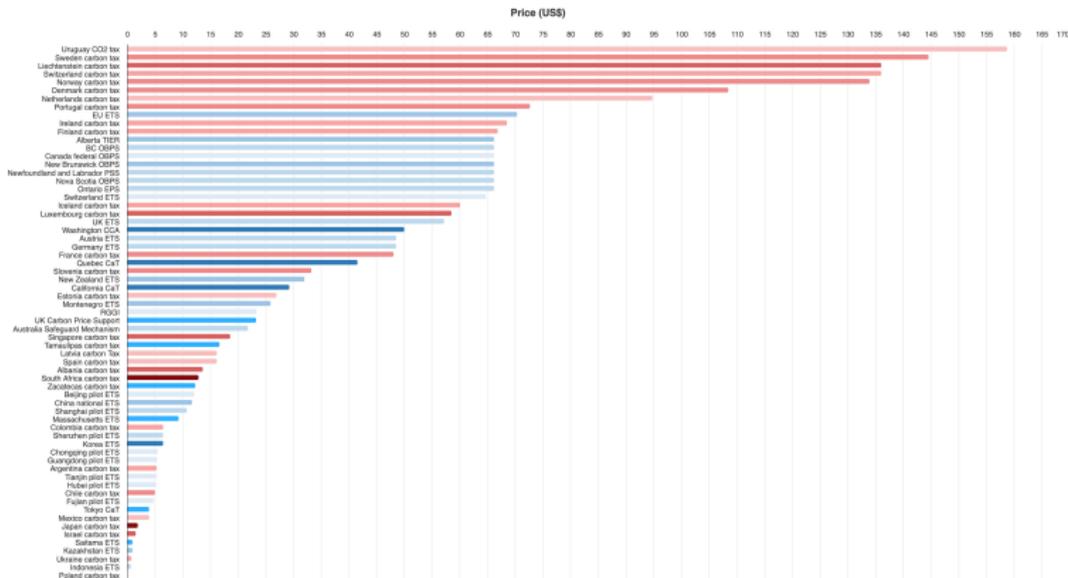


Figure: Carbon prices (World Bank, 2025)

# 2. Optimal pollution and internalization of the externalities

## Standards:

- Emission standards (uniform restrictions on pollution emissions)
- Quality or performance standards (restrictions on pollution per unit of output )
- Process standards (restrictions of the use of a polluting input / mandated use of a particular pollution-control technology)

## 2. Optimal pollution and internalization of the externalities

### *Market-based Instruments (1)* $\equiv$ Pigouvian tax (**Pigou, 1920**)

- What is the tax rate  $\tau$  that enables obtaining the optimal level of externality but through the decentralized equilibrium?  
Each firm maximizes its profit

$$\begin{aligned} \max_{e_i} \pi^i(e_i) - \tau e_i &\iff \pi_m^i(e_i^*) = \tau \quad \forall i \\ \implies \tau^* &= D_m(E^*) \end{aligned}$$

## 2. Optimal pollution and internalization of the externalities

### Pigouvian tax (Pigou 1920)

- Tax basis
  - Polluting emissions: eg. greenhouse gas ( $\text{CO}_2$ , methane, etc)
  - If impossible, products whose use causes pollution : eg.  $\text{CO}_2$  is due to combustion of fossil energies (oil, coal, natural gas) whose emission coefficients are well known (stoichiometric proportions)  
↳ Effective tax basis: consumption of fossil energies
- Tax rate

Internalisation of the externality will be achieved if the tax rate is equal to the marginal damage caused by the polluting emissions.

## 2. Optimal pollution and internalization of the externalities

### Pigovian tax (Pigou 1920)

- Principle: **price-signal**
    - Objective :giving incentives to use or activity substitutions
    - Internalisation leads the polluter to trade off between 2 possibilities:
      - Pay the tax rate for each unit of pollution emitted
      - Decrease its polluting emissions in order to reduce its tax burden
- ⇨ *The polluter will choose to decrease its pollution as long as its marginal abatement cost is less than the unit tax rate, but it will pay the tax burden due to the part of its pollution that would be too costly to avoid.*
- Complies with the **polluter-pays principle** (OECD, 1972)
    - Contrary to abatement subsidies

## 2. Optimal pollution and internalization of the externalities

*Market-based Instruments (2)*  $\equiv$  abatement subsidies

- What is the subsidy rate  $s$  that enables obtaining the optimal level of externality but through the decentralized equilibrium?  
Each firm maximizes its profit and finds profitable to reduce its emissions as long as  $s \geq \pi_m^i(e_i)$

$$\begin{aligned} \max_{e_i} \pi^i(e_i) + s(e^D - e_i) &\iff \pi_m^i(e_i^*) = s \quad \forall i \\ \implies s^* = \tau^* = D_m(E^*) \end{aligned}$$

## 2. Optimal pollution and internalization of the externalities

### Market-based Instruments (3) $\equiv$ cap-and-trade (CAP)

- Basic principle: *quantity-signal*
  - Objective : giving incentives to substitutions (consumptions or activities)
  - Principle : distribution (for free / auctions) of emission permits, in a given quantity lower than pollution without regulation  
 $\iff$  Modifies agents' behaviors, as well as the pigovian tax (market price = tax rate)
- When permits are distributed for free, the "fiscal burden" is lower than for the tax

$$\bar{Q} = E^* = \sum_{i=1}^I e_i^*$$

Each firm receives quantity  $\bar{q}_i$  and may buy or sell permits, by maximizing its profit

$$\max_{e_i} \pi^i(e_i) - p(e_i - \bar{q}_i) \iff p^* = \pi_m^i(e_i^*) = D_m(E^*) \quad \forall i$$

## 2. Optimal pollution and internalization of the externalities

### Is a policy really necessary? Coase Theorem

#### *Definition of property rights on environment*

- If property rights are defined on the environment
- If direct bargaining is possible between the polluter and the polluted
- There is no need of any government intervention to achieve optimality

$$D_m(E^*) = \pi_m^i(e_i^*) \quad \forall i$$

- **This result does not depend on the initial allocation of the property rights**

# 2. Optimal pollution and internalization of the externalities

## Limits to the Coase Theorem:

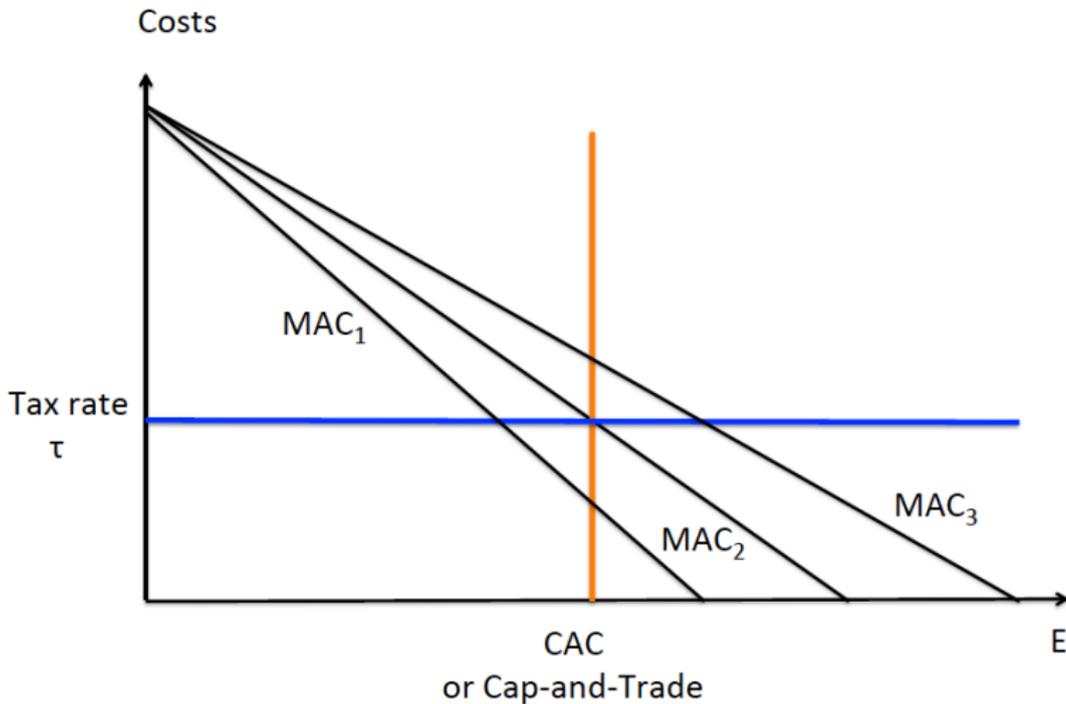
- Existence of any private information about the abatement costs and the damage
- Existence of transaction costs
- Great number of participants
- How to negotiate between generations ?

↪ **The Coase Theorem should be rather used as "because of transaction costs and/or private information, the optimal solution cannot be implemented without any government intervention"**

# 3. Comparison between instruments

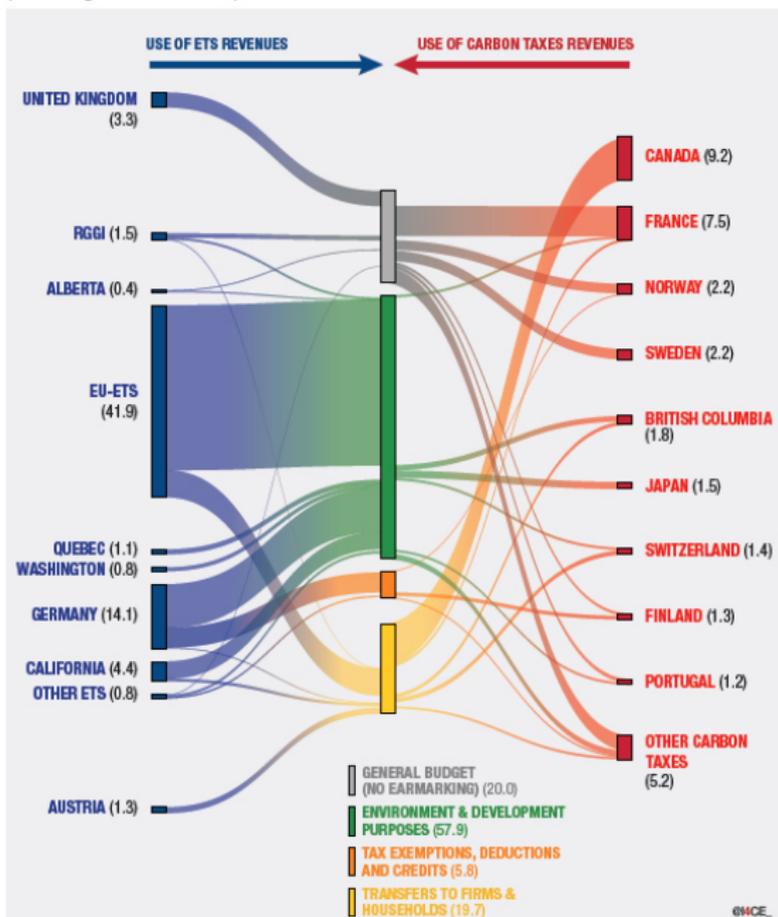
## Efficiency

Market-based instruments (tax and CAP), contrary to standards, minimize regulation costs, by *equalizing marginal abatement costs*



### CARBON REVENUE USE IN 2024\*

(amounts given in billion USD)



## 3. Comparison between instruments

Recycling the tax revenue: a possible *double dividend*

- An environmental tax is incitative (first *dividend*) and not intended primarily to raise the total tax revenues: budget neutrality principle (recycling of the environmental tax revenues)
- In a sub-optimal tax system – with distortionary taxes – recycling the revenues of the environmental tax by reducing another tax may allow to reduce the existing distortions and thus improve the economic welfare (Goulder [1995]): *second dividend*
  - Replacing a distortionary tax with an environmental tax yields always (in partial equilibrium) a welfare gain relative to a lump-sum compensation
  - Results depend on the relative size of 2 effects : the recycling effect and the tax-interaction effect
  - In France, labor taxes are the most distortionary (and not capital taxes, as in US or UK): reducing their rate gives the highest probability to obtain a double dividend.

## 3. Comparison between instruments

**Pigovian tax / subsidies**       $s^* = \tau^* = D_m(E^o)$

- Same environmental effectiveness
- Subsidy : cost bearing on the government's expenditures, *in fine* on the polluted (conflicting with the polluter pays principle)
- Tax : the revenue can be recycled (existence of a double dividend?)
- Seemingly opposite effects on the competitiveness of the firms (but risk for subsidies of maintaining inefficient firms)

### 3. Comparison between instruments

#### Subsidies and industry equilibrium

$$\begin{aligned} \pi^i(e_i) &\mapsto \pi^i(e_i) + s(e^D - e_i) \quad \text{eg } e_i = x_i \\ \iff \begin{cases} C_M^i(e_i) &\mapsto C_M^i(e_i) - s(x^D - x_i)/x_i \\ C_m^i(e_i) &\mapsto C_m^i(e_i) + s \end{cases} \end{aligned}$$

The subsidy increases the marginal cost of emissions but decreases the average production cost:

$\implies$  *Exit of less profitable firms because of their high emission rate is prevented*

$\implies$  *Global pollution decreases less than under a tax*

# 3. Comparison between instruments

**Pigovian tax / CAP**       $p^* = \tau^* = D_m(E^*)$

- Same environmental effectiveness
- Properties depend on how permits are allocated: for free or auctions
- Gross cost of permits lower than tax burden, if they are given for free
- Tax revenues can be recycled (double dividend) as well as auction revenues, unless permits are given for free
- Similar impacts on firms competitiveness

## 3. Comparison between instruments

### Impact of tax and CAP on competitiveness

Taxes, as well as any other environmental regulation tool, increase firms' costs leading them to pass through these increase in prices.

- Possible loss of market share and deterioration of the trade balance
- Risk of relocations: pollution haven
  - Production relocation  $\implies$  pollution relocation?
  - No clear empirical evidence
- ... but Porter hypothesis (incentive to innovate and to propose new products, that yield gains of competitiveness due to higher quality)

↷ Debate about the *border tax*.

# 3. Comparison between instruments: Dynamic efficiency

## *Tax vs standards*

**The incentives to innovate are greater under tax (or under cap-and-trade) than under standards.**

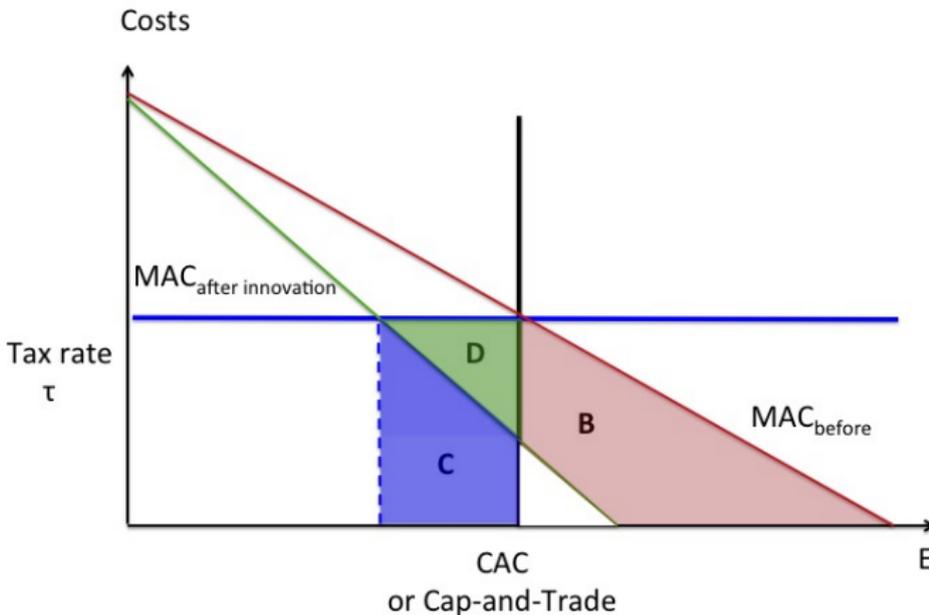
Assumption for the graphical 'proof':

- for a given level of output, the polluting firm may choose to adopt a cleaner technology
- the new technology is characterized by a lower marginal abatement cost for each unit of emissions (pollution is less profitable under the new technology)

# 3. Comparison between instruments: Dynamic efficiency

*Tax vs standards: adoption gain*

- Standards: abatement cost avoided  $\Delta C(a) = B$
- Tax:  $\Delta C(a) = (B - C)$  and tax burden  $\Delta T(e) = (C + D) \implies$   
Overall Gain =  $B + D > B$



### 3. Comparison between instruments: Distributive effects (Fullerton, 2001)

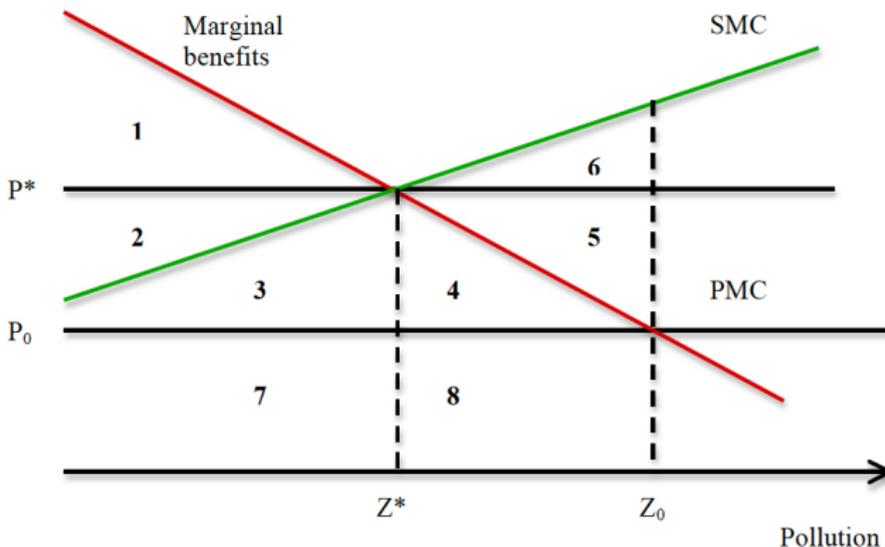
*General equilibrium model (but exposed as a partial equilibrium model)*

Assumptions:

- Private cost per unit of emissions fixed at price  $P_0$  = cost of resources necessary for removal and disposal of these emissions (waste)
- Fixed demand curve for these emissions = marginal benefit of this pollution to production = "*willingness to pay for the right to pollute*"
- Lump-sum taxes are available: the government can obtain the necessary revenue without using distortionary taxes (labor taxes or capital taxes)

# 3. Comparison between instruments: Distributive effects (Fullerton, 2001)

*Pigovian tax on pollution*



Consumers:  $-(2 + 3 + 4)$   
 Firms' profit: 0  
**Overall Net Effect: 5 + 6**

Government revenues:  $2 + 3$   
 Victims:  $4 + 5 + 6$

### 3. Comparison between instruments: Distributive effects (Fullerton, 2001)

#### *Welfare gains and losses*

	Consumers	Firms	Gov.	Victims
Pigovian tax on pollution	$-(2 + 3 + 4)$	0	$2 + 3$	$4 + 5 + 6$
Pigovian subsidy	$-(2 + 3 + 4)$	$2 + 3 + 4 + 5$	$-(4 + 5)$	$4 + 5 + 6$
CAP: Free permits	$-(2 + 3 + 4)$	$2 + 3$	0	$4 + 5 + 6$
CAP: Auctioned permits	$-(2 + 3 + 4)$	0	$2 + 3$	$4 + 5 + 6$
CAC: Quantity restriction	$-(2 + 3 + 4)$	$2 + 3$	0	$4 + 5 + 6$
CAC: Quantity and price	-4	0	0	$4 + 5 + 6$

**Overall Net Effect: 5 + 6 in any case**

## 4. Focus on the distributive effects of carbon pricing

*Are carbon taxes regressive?*

- The debate over a green tax shift has focused on *efficiency* but *distributional concerns* limit political support for environmental taxes
- Environmental taxes by themselves are usually considered as *regressive taxes* since they hurt the poorest households relatively harder, as these households are constrained to devote a larger share of their income to the consumption of polluting goods.
- These are often necessary goods, like energy products used for transportation or heating (Poterba [1991], Metcalf [1999], Wier et al. [2005], Ruiz and Trannoy [2008]).
- As these expenditures are constrained, and because poor households are not able to invest in less polluting vehicles or boilers, their substitution behavior is limited and they are unable to limit their loss of purchasing power.

## 4. Focus on the distributive effects of carbon pricing

### *Are carbon taxes regressive?*

- Poterba (1991): tax incidence is measured by modelling only accounting effects (holding everything else constant: no tax base erosion, no macroeconomic / intersectoral effects)
  - energy taxes are
    - regressive when computing effort rates as a function of the disposable income,
    - but almost not when effort rates measured as a function of total expenditures (used as a proxy of lifetime income)
  - Hamilton and Cameron (1994) for Canadian households
  - Wier et al. (2005): idem for Denmark
  - Dinan and Rogers (2002): idem for the Netherlands
  - Kerkhof et al. (2008) and Shammin and Bullard (2009): idem for the United States.

# 4. Focus on the distributive effects of carbon pricing

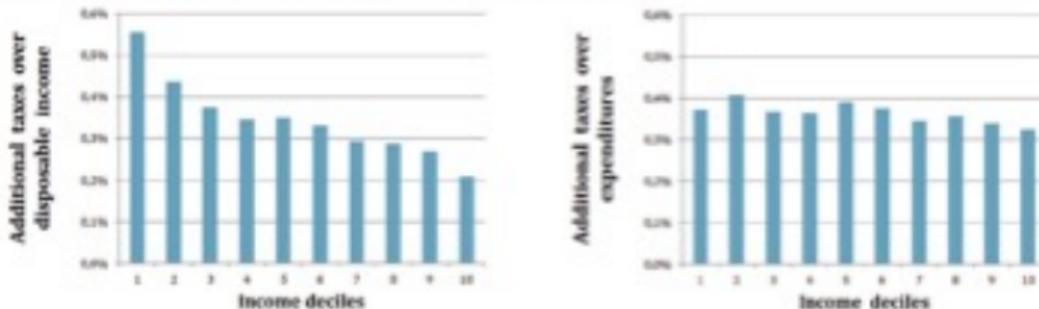
*Are carbon taxes regressive? Douenne (2020)*

- ex ante analysis of the increase in the carbon price implemented by law in France in 2018
- considers
  - vertical distributive effects  $\equiv$  between households along the income dimension
  - horizontal distributive effects  $\equiv$  between households with similar income  
(households living in rural areas and smaller cities spend on average more in energies, both for transport and housing)
- study based on a micro-simulation model of indirect taxation for French households
  - with estimated price elasticities

# 4. Focus on the distributive effects of carbon pricing

*Are carbon taxes regressive? Douenne (2020)*

Figure 2: Average effort rate on the policy, by income decile.

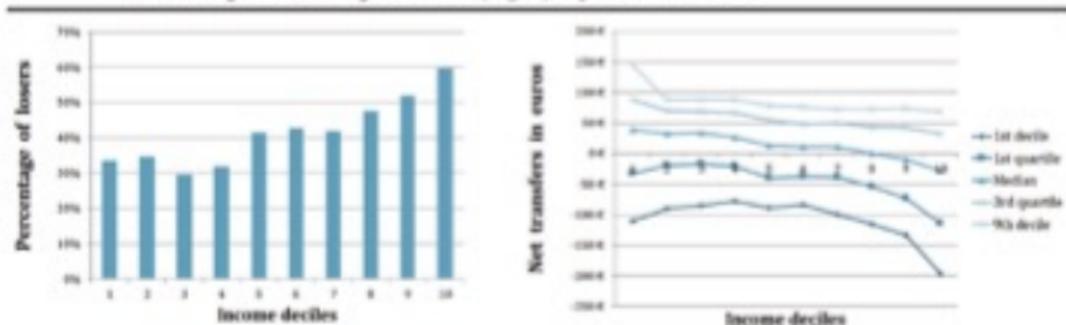


Lecture: For households belonging to the 1st income decile, the increase in energy taxes following the policy will represent 0.55% of their disposable income, against 0.21% for those in the last income decile. As a share of their total expenditures, it represents respectively around 0.37% and 0.32%.

# 4. Focus on the distributive effects of carbon pricing

*Are carbon taxes regressive? Douenne (2020)*

Figure 4: Share of households financially losing from the reform (left), and distribution of net transfers per consumption unit (right), by income decile.



Lecture: After flat-recycling, 34% of households belonging to the 1st income decile are expected to receive negative net transfers from the policy (left), including 25% losing more than 32€ per consumption unit (right).

## 4. Focus on the distributive effects of carbon pricing

### *The role of the sources side effect*

↷ But all these studies have considered only the *uses side effect*, ignoring the impact of green taxes on factor incomes, and thus on inequality

- Fullerton and Heutel (2010) have shown that environmental policies can harm the remuneration of capital more than that of labor:
  - the polluting industries are relatively more capital intensive than other industries
  - implementing policies that affect them negatively is detrimental to the factor they use most intensively
    - ⇒ from the factor income perspective alone, an energy tax can be progressive, as the income of the richest households are more hurt than those of the poor.
- Even in the case that a carbon tax reduces the welfare of all households, it can still be progressive, if the rich are more negatively affected than the poor.

# 4. Focus on the distributive effects of carbon pricing

*The role of the sources side effect: Dissou and Siddiqui (2015)*

- Static, multisector, small open computable general equilibrium model for the Canadian economy
- Carbon taxes tend to
  - reduce inequalities through the changes in factor prices
  - increase inequalities through the changes in commodity prices

# 4. Focus on the distributive effects of carbon pricing

*How can environmental tax reforms (ETR) avoid regressivity?*

- Environmental tax reforms combine green taxes with reductions in other taxes
  - can the regressivity of the green tax be offset by increased progressivity resulting from other tax cuts?
  - lump-sum transfers may restore progressivity: but, contrary to the *chèque énergie*, they should not allow energy consumption for free.

## 4. Focus on the distributive effects of carbon pricing

*How can environmental tax reforms (ETR) avoid regressivity? Metcalf (1999)*

- U.S. ETR incidence analysis, modelling only accounting effects (holding everything else constant: no tax base erosion, no macroeconomic / intersectoral effects), like Poterba (1991)
- distributional results assessed both according to an annual income measure and a lifetime income measure
- Results:
  - an ETR shifting 10% of federal revenues from payroll tax and personal income tax towards environmental tax has a *negligible* impact on the income distribution
  - any distributional concerns can be addressed through tax reductions targeted to low-income households

## 4. Focus on the distributive effects of carbon pricing

*Can equity be compatible with efficiency? Aubert and Chiroleu-Assouline (2019)*

- Theoretical analysis of the distributive effects of an energy tax
- General equilibrium model, except for the labor market (unemployment: job search model à la Pissarides (1994))
  - heterogenous agents (regarding their skills and thus their wage and bargaining power)
  - low-skilled unemployment and thus discrete labour supply, but intensive supply of high-skilled workers
  - subsistence level of consumption of polluting goods

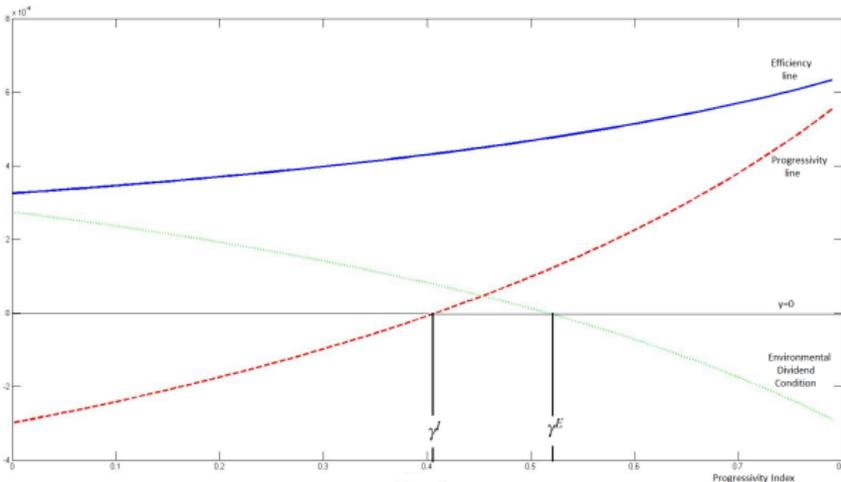
## 4. Focus on the distributive effects of carbon pricing

*Can equity be compatible with efficiency? Aubert and Chiroleu-Assouline (2019)*

- Results:
  - In the case where the revenue-neutral ETR appears to be regressive, the gains from the double dividend can be made Pareto improving by using a redistributive non-linear income tax if redistribution is initially not too large, and if the subsistence level of polluting consumption is not too high.
  - Moreover, the use of a non-linear income tax acts on unemployment, which can moderate the trade-off between equity and efficiency.
- Revenue recycling rule of the green tax receipts through labor tax cut ( $-da$  in average):
  - $dt_L = (1 + \gamma)da$  to the low-skilled workers
  - $dt_H = (1 - \gamma)da$  to the high-skilled workers

## 4. Focus on the distributive effects of carbon pricing

*Can equity be compatible with efficiency? Aubert and Chiroleu-Assouline (2019)*



If the progressivity index  $\gamma > \gamma^E = 0,58$ , there is no environmental dividend.

If the progressivity index  $\gamma < \gamma^I = 0,40$ , the reform is regressive.