Lecture 2.a: Instrument choice for climate policies: efficiency

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What we did so far

Last week, we have:

- described climate change as a phenomenon: its causes and its consequences;
- characterized how the climate and the economy are intertwined, due to:
  - the economic origins of climate change;
  - the economic impacts of climate change;
- discussed the different climate-economic scenarios that society may face in the future.

What we now want to do

Questions: can we choose between these scenarios? How?

- Choosing between different scenarios for societies is what politics is meant for.
- Policymakers use policies to trigger society towards a certain path.
- In face of climate change, climate policies can be implemented.

New questions: what are those policies? What do they achieve? Is there one better than the others?

Objective of the lecture

Today, we will attempt to answer these questions

- What are those policies? $\rightarrow$ Countless possibilities, but can be grouped in broad categories with common features.
- What do they achieve? $\rightarrow$ Depending on their features, we can identify a certain pattern of consequences.
- Is there one better than the others? $\rightarrow$ Generally no, this is largely case specific. Still, we can draw a number of important lessons from their comparison.

$\rightarrow$ The goal is to provide a framework to think about how different policies work, and use it to compare their relative merits in various contexts.

Comparing policy instruments: which criteria?

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Comparing policy instruments: which criteria?

There are usually three aspects that policymakers need to assess to compare the merit of climate policies:

- their efficiency (aka their "cost-effectiveness");
- their equity (aka their distributional effects);
- their feasibility (*i.e.* their support by the public or other stakeholders).

→ Today we focus on the first aspect. The second and third will be covered in the next two lectures.

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Three concepts: efficiency, optimality, sustainability

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Three concepts: efficiency, optimality, sustainability

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- Optimality.
  - An allocation of resources is said to be optimal according to a certain Social Welfare Function it is maximizes this Social Welfare Function.

Three concepts: efficiency, optimality, sustainability

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- Efficiency.
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- Optimality.
  - An allocation of resources is said to be optimal according to a certain Social Welfare Function it is maximizes this Social Welfare Function.
- Sustainability.
  - No generally accepted definition.
  - One candidate would be: An allocation of resources is said to be sustainable if it ensures that resources remain above a certain threshold in any future period of time.

Efficiency

For an allocation to be efficient in an economy, three conditions must be met:

1. efficiency in consumption;
   - MRS must be equalized
2. efficiency in production;
   - MRT must be equalized
3. product-mix efficiency.
   - MRS must be equal to MRT

A simple economy

Assumptions: to keep things simple, let's assume the economy is made of:

- two final goods X and Y;
- each produced by two firms 1 and 2;
- produced from two inputs K and L;
- and consumed by two individuals A and B.

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- two final goods X and Y;
- each produced by two firms 1 and 2;
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- and consumed by two individuals A and B.

We can write the utility functions of individual A and B as:

$$U^A(X^A, Y^A) \quad ; \quad U^B(X^B, Y^B)$$

and the production function of goods X and Y by firms 1 and 2 as:

$$X_1(K_1^X, L_1^X) \quad ; \quad Y_1(K_1^Y, L_1^Y)$$
$$X_2(K_2^X, L_2^X) \quad ; \quad Y_2(K_2^Y, L_2^Y)$$

(everything we will show can easily be extended to an arbitrarily large number of individuals, firms, goods, and inputs)

Efficient allocation: the problem

To study efficient allocations, we apply the Pareto principle: we maximize the utility of a given individual (1) subject to other individuals' utility being higher than a given threshold (2). In our case, this gives:

$$\max_{X^A, Y^A} U^A(X^A, Y^A) \tag{1}$$

subject to:

$$U^B(X^B, Y^B) \geq \bar{U} \tag{2}$$

$$X_1(K_1^X, L_1^X) + X_2(K_2^X, L_2^X) \geq X^A + X^B \tag{3}$$

$$Y_1(K_1^Y, L_1^Y) + Y_2(K_2^Y, L_2^Y) \geq Y^A + Y^B \tag{4}$$

$$K \geq K_1^X + K_2^X + K_1^Y + K_2^Y \tag{5}$$

$$L \geq L_1^X + L_2^X + L_1^Y + L_2^Y \tag{6}$$

where output consumed cannot exceed output produced (3 and 4), and inputs used cannot exceed inputs available (5 and 6).

Efficient allocation: the problem

The previous problem can be solved using the following Lagrangian:

$$\begin{aligned}
\mathcal{L} = U^A(X^A, Y^A) &+ \lambda_1(U^B(X^B, Y^B) - \bar{U}) \\
&+ \lambda_2(X_1(K_1^X, L_1^X) + X_2(K_2^X, L_2^X) - X^A - X^B) \\
&+ \lambda_3(Y_1(K_1^Y, L_1^Y) + Y_2(K_2^Y, L_2^Y) - Y^A - Y^B) \\
&+ \lambda_4(K - K_1^X - K_2^X - K_1^Y - K_2^Y) \\
&+ \lambda_5(L - L_1^X - L_2^X - L_1^Y - L_2^Y)
\end{aligned}$$

Efficiency in consumption

First order conditions:

$$\frac{\partial \mathcal{L}}{\partial X^A} = \frac{\partial U^A}{\partial X^A} - \lambda_2 = 0 \tag{7}$$

$$\frac{\partial \mathcal{L}}{\partial Y^A} = \frac{\partial U^A}{\partial Y^A} - \lambda_3 = 0 \tag{8}$$

$$\frac{\partial \mathcal{L}}{\partial X^B} = \lambda_1 \frac{\partial U^B}{\partial X^B} - \lambda_2 = 0 \tag{9}$$

$$\frac{\partial \mathcal{L}}{\partial Y^B} = \frac{\partial U^B}{\partial Y^B} - \lambda_3 = 0 \tag{10}$$

If we rearrange these conditions we obtain:

$$\frac{\frac{\partial U^A}{\partial X^A}}{\frac{\partial U^A}{\partial Y^A}} = \frac{\lambda_2}{\lambda_3} = \frac{\frac{\partial U^B}{\partial X^B}}{\frac{\partial U^B}{\partial Y^B}} \tag{11}$$

$\rightarrow$ Consumption efficiency requires that marginal rates of utility substitution equalize.

Efficiency in consumption

Graphically:

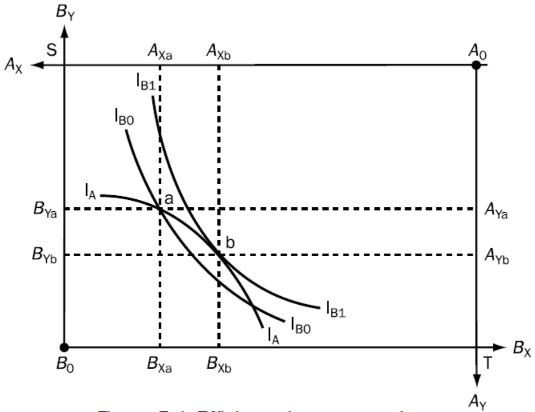

Figure 5.1 Efficiency in consumption

Source: Perman et al.

Efficiency in consumption

Graphically:

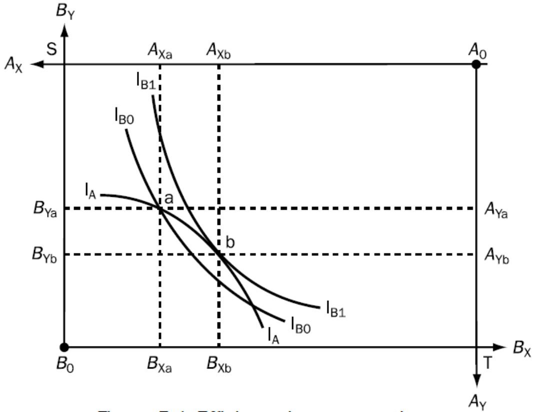

Figure 5.1 Efficiency in consumption

Source: Perman et al.

$\rightarrow$ a is not an efficient allocation because B can be made better off without hurting A. b is efficient because we cannot make A or B better off without hurting the other. The two indifferent curves have identical slopes at b.

Efficiency in production

Similarily, one can take the first order conditions w.r.t. K_1^X, K_2^X, L_1^X, L_2^X, K_1^Y, K_2^Y, L_1^Y, L_2^Y and show that production efficiency requires that marginal rates of technical substitution equalize (see Perman et al, appendix of chapter 5):

$$\frac{\frac{\partial X_1}{\partial L_1^X}}{\frac{\partial X_1}{\partial K_1^X}} = \frac{\frac{\partial X_2}{\partial L_2^X}}{\frac{\partial X_2}{\partial K_2^X}} = \frac{\frac{\partial Y_1}{\partial L_1^Y}}{\frac{\partial Y_1}{\partial K_1^Y}} = \frac{\frac{\partial Y_2}{\partial L_2^Y}}{\frac{\partial Y_2}{\partial K_2^Y}} \tag{12}$$

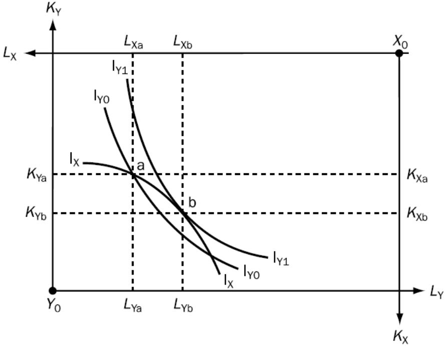

Figure 5.2 Efficiency in production

Source: Perman et al.

Product-mix efficiency

Finally, rearranging the FOCs one can also show that for an allocation to be efficient, the marginal rates of transformation must equalize the marginal rate of utility substitution:

$$\frac{\frac{\partial Y}{\partial K}}{\frac{\partial X}{\partial K}} = \frac{\frac{\partial Y}{\partial L}}{\frac{\partial X}{\partial L}} = \frac{\frac{\partial U^A}{\partial X^A}}{\frac{\partial U^A}{\partial Y^A}} = \frac{\frac{\partial U^B}{\partial X^B}}{\frac{\partial U^B}{\partial Y^B}} \tag{13}$$

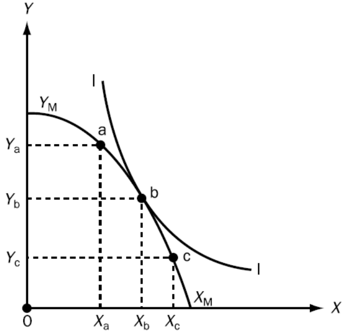

Figure 5.3 Product-mix efficiency

Source: Perman et al.

Multiple efficient allocations

An efficient allocation is by no mean unique: in the figure below, all allocations on the CC curve are efficient $\rightarrow$ for all these allocations, it is not possible to increase the utility of A or B without hurting the other.

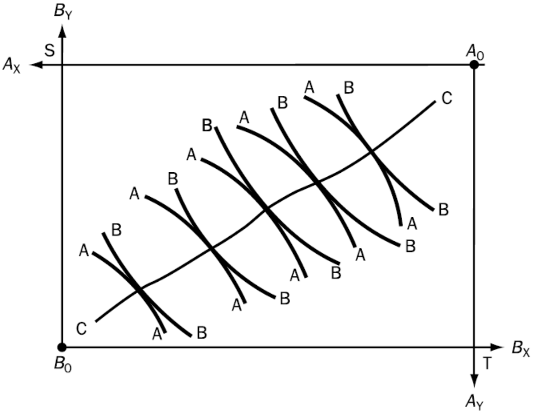

Figure 5.4 The set of allocations for consumption efficiency

Source: Perman et al.

The social welfare function and optimal allocations

Social welfare function: it is a function that ranks allocations according to their level of social desirability. In our case, a social welfare function takes the form $W = W(U^A, U^B)$ and is non-decreasing in both arguments. At the optimum we must have:

$$\frac{\frac{\partial W}{\partial U_A}}{\frac{\partial W}{\partial U_B}} = \frac{\frac{\partial U_B}{\partial X_B}}{\frac{\partial U_A}{\partial X_A}} = \frac{\frac{\partial U_B}{\partial Y_B}}{\frac{\partial U_A}{\partial Y_A}}$$

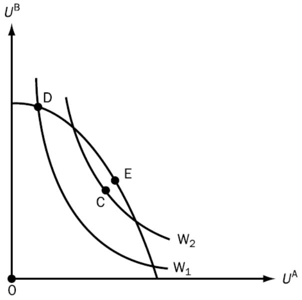

Figure 5.7 Welfare and efficiency

Source: Perman et al.

Effiency, optimality, and the benefits of a reform

Note: in the previous figure, allocation C is preferred to D, yet D is efficient while C is not. E is efficient and is preferred to both C and D. $\rightarrow$ Improving economic efficieny will not always lead to a more desirable social outcome.

How to decide whether a reform is desirable?

Effiency, optimality, and the benefits of a reform

<u>Note:</u> in the previous figure, allocation C is preferred to D, yet D is efficient while C is not. E is efficient and is preferred to both C and D. $\rightarrow$ Improving economic efficieny will not always lead to a more desirable social outcome.

<u>How to decide whether a reform is desirable?</u>

- Option 1: compare the outcome of the SWF W with the *ex ante* and *ex post* allocations and implement the reform *iff* social welfare increases $\rightarrow$ Problem: ideally, the social planner knows the SWF. In practice, institutions reflect imperfectly social preferences and there is no straightforward rule to aggregate them.
- Option 2: implement a reform *iff* it is Pareto improving. $\rightarrow$ Problem: situations in which Pareto improvements are possible are very scarce.
- Option 3: implement a reform *iff* the winners can compensate the losers and still be better off (Kaldor-Hicks improvement). $\rightarrow$ Problem: if these transfers are theoretically possible but do not happen, tensions may emerge between winners and losers.

Sustainability

Different ways to define it: non-decreasing welfare, minimal level of welfare in each period, etc.

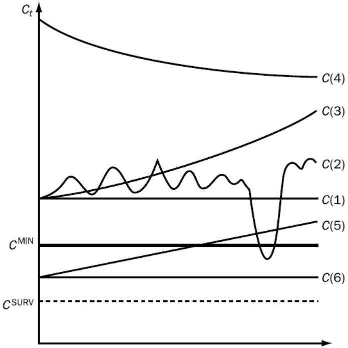

Figure 4.1 Consumption paths over time

Source: Perman et al.

Question: which of these paths do you consider sustainable? How does that relate to their desirability?

Sustainability

Different ways to define it: non-decreasing welfare, minimal level of welfare in each period, etc.

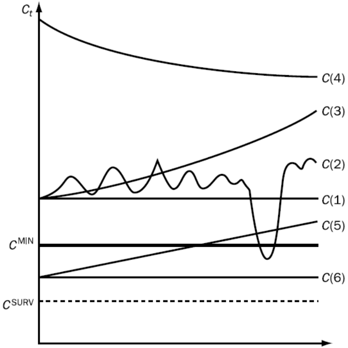

Figure 4.1 Consumption paths over time

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Question: which of these paths do you consider sustainable? How does that relate to their desirability? Conceptually, not as well defined as the two previous concepts.

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First welfare theorem

Assumptions: Let's consider a competitive economy characterized by the following assumptions:

- markets are complete;
- markets are perfectly competitive;
- agents have perfect information;
- all resources are subject to private property rights;
- there are no externalities;
- there are no public goods;
- utility and production functions are "well-behaved".
- consumers maximize their utility, firms maximize their profits.

Theorem

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- utility and production functions are "well-behaved".
- consumers maximize their utility, firms maximize their profits.

Theorem (not a formal statement): *any equilibrium allocation is Pareto efficient.* In our case, it can be shown that market forces lead to the equalization of the MRT, MRS, and relative prices:

$$\frac{\frac{\partial Y}{\partial K}}{\frac{\partial X}{\partial K}} = \frac{\frac{\partial Y}{\partial L}}{\frac{\partial X}{\partial L}} = \frac{P_X}{P_Y} = \frac{\frac{\partial U^A}{\partial X^A}}{\frac{\partial U^A}{\partial Y^A}} = \frac{\frac{\partial U^B}{\partial X^B}}{\frac{\partial U^B}{\partial Y^B}} \tag{14}$$

First welfare theorem: caveats

The first welfare theorem is a very strong result that sets a useful benchmark to understand markets' properties. Two caveats are in order:

1. The previous assumptions are extremely strong: these assumptions depict an idealized economy. In reality they are never fully met. Thus, we can hardly expect market equilibria to actually produce efficient allocations.
2. Efficiency is not optimality: under the previous assumptions, a competitive equilibrium will be efficient. This says nothing about its optimality or social desirability.

→ These two points suggest that economic policies will have two critical roles: (1) restoring efficiency, (2) redistributing resources to get closer to optimality.

In this class: we will focus on the first aspect, as climate change generates an externality. Still, redistributive issues can generally not be separated from efficiency (see lecture 2.b).

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Externalities: definition and classification

One particular case of market failure is the existence of externalities, i.e. situations in which individuals produce by their actions external effects that affect the well-being of other individuals, without any counterpart. They can be classified as follows:

Table 5.6 Externality classification

Arising in	Affecting	Utility/production function
Consumption	Consumption	$U^A(X^A, Y^A, X^B)$
Consumption	Production	$X(K^X, L^X, Y^A)$
Consumption	Consumption and production	$U^A(X^A, Y^A, X^B)$ and $Y(K^Y, L^Y, X^B)$
Production	Consumption	$U^A(X^A, Y^A, X)$
Production	Production	$X(K^X, L^X, Y)$
Production	Consumption and production	$U^A(X^A, Y^A, Y)$ and $X(K^X, L^X, Y)$

Source: Perman et al.

Externalities: a formal example

Let's consider an endowment economy—that is a simplified version of our production economy—with two consumers A and B and two goods X and Y. Assuming no externality, the utility of A and B can be expressed as:

$$U^A(X^A, Y^A) \quad ; \quad U^B(X^B, Y^B)$$

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$$U^A(X^A, Y^A) \quad ; \quad U^B(X^B, Y^B)$$

Let's now assume that when A consumes good X, it also affects the welfare of B. Then, their respective utility functions write:

$$U^A(X^A, Y^A) \quad ; \quad U^B(X^B, Y^B, {\color{red}X^A})$$

$\rightarrow$ X^A now enters the utility of B, but X^A is still chosen by A only.

Efficient allocation with a consumption externality

The objective is to maximize $U^A(X^A, Y^A)$, subject to:

- $U^B(X^B, Y^B, X^A) \geq \bar{U}$
- $\bar{X} \geq X^A + X^B$
- $\bar{Y} \geq Y^A + Y^B$

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- $\bar{Y} \geq Y^A + Y^B$

We write the following Lagrangian:

$$\mathcal{L} = U^A(X^A, Y^A) + \lambda_1(U^B(X^B, Y^B, X^A) - \bar{U}) + \lambda_2(\bar{X} - X^A - X^B) + \lambda_3(\bar{Y} - Y^A - Y^B)$$

Efficient allocation with a consumption externality

The first order conditions give:

$$\frac{\partial L}{\partial X^A} = \frac{\partial U^A}{\partial X^A} + \lambda_1 \frac{\partial U^B}{\partial X^A} - \lambda_2 = 0 \quad (15)$$

$$\frac{\partial L}{\partial X^B} = \lambda_1 \frac{\partial U^B}{\partial X^B} - \lambda_2 = 0 \quad (16)$$

$$\frac{\partial L}{\partial Y^A} = \frac{\partial U^A}{\partial Y^A} - \lambda_3 = 0 \quad (17)$$

$$\frac{\partial L}{\partial Y^B} = \lambda_1 \frac{\partial U^B}{\partial Y^B} - \lambda_3 = 0 \quad (18)$$

(+ Kuhn-Tucker conditions)

Efficient allocation with a consumption externality

Substituting, we get:

$$\frac{\partial U^B}{\partial X^B}\frac{\partial Y^B}{\partial U^B} = \frac{\partial U^A}{\partial X^A}\frac{\partial Y^A}{\partial U^A} + \lambda_1 \frac{\partial U^B}{\partial X^A}\frac{\partial Y^A}{\partial U^A} \tag{19}$$

Efficient allocation with a consumption externality

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$$\frac{\partial U^B}{\partial X^B}\frac{\partial Y^B}{\partial U^B} = \frac{\partial U^A}{\partial X^A}\frac{\partial Y^A}{\partial U^A} + \lambda_1 \frac{\partial U^B}{\partial X^A}\frac{\partial Y^A}{\partial U^A} \tag{19}$$

Equation (19) above is necessary to obtain an efficient allocation in this economy. The red term corresponds to the externality created by the consumption of X^A on consumer B. The social impact of this consumption is therefore different than its private impact.

Market equilibrium allocation with a consumption externality

Objective : agent $i = A, B$ maximizes U^i under its budget constraint, that is, $w_i \geq pX^i + Y^i$ where p is the price of X and Y is the numéraire. The two Lagrangians write:

$$\mathcal{L}^A = U^A(X^A, Y^A) + \lambda(w^A - pX^A - Y^A) \tag{20}$$

$$\mathcal{L}^B = U^B(X^B, Y^B, X^A) + \lambda(w^B - pX^B - Y^B) \tag{21}$$

Since A only decides on X^A and Y^A and B only decides on X^B and Y^B, for $i = A, B$ the FOCs give:

$$\frac{\partial \mathcal{L}^i}{\partial X^i} = \frac{\partial U^i}{\partial X^i} - \lambda p = 0 \tag{22}$$

$$\frac{\partial \mathcal{L}^i}{\partial Y^i} = \frac{\partial U^i}{\partial Y^i} - \lambda = 0 \tag{23}$$

(+ Kuhn-Tucker conditions) which leads to:

$$p = \frac{\partial U^B}{\partial X^B}\frac{\partial Y^B}{\partial U^B} = \frac{\partial U^A}{\partial X^A}\frac{\partial Y^A}{\partial U^A} \neq \frac{\partial U^A}{\partial X^A}\frac{\partial Y^A}{\partial U^A} + \lambda\frac{\partial U^B}{\partial X^A}\frac{\partial Y^A}{\partial U^A} \tag{24}$$

$\rightarrow$ the competitive equilibrium (on the left of $\neq$) ignores the externality, and therefore leads to an inefficient allocation.

Equilibrium *vs.* Efficient allocation

An efficient allocation should include all activities whose social benefit (including private benefits) exceeds the social cost (including private costs) $\rightarrow$ generally achieved by equating marginal **social** costs and benefits.

The market equilibrium leads individuals (producers, consumers) to perform activities as long as their private marginal benefits exceed their private marginal cost $\rightarrow$ generally achieved by equating marginal **private** costs and benefits.

A simple example

Let's take a very simple example. Let's assume we have two individuals 1 and 2, one of them (say 1) can chose the quantity x of a polluting good it consumes.

- The utility of 1 is $U_1(x) = B(x) - C(x)$ where $B(x)$ and $C(x)$ are 1's private benefits and costs from consuming x;
- The utility of 2 is $U_2(x) = \bar{u} - D(x)$ where $\bar{u}$ is exogenous and $D(x)$ is the external effect of the consumption of x by individual 1.

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- The utility of 2 is $U_2(x) = \bar{u} - D(x)$ where $\bar{u}$ is exogenous and $D(x)$ is the external effect of the consumption of x by individual 1.

$\rightarrow$ Equilibrium allocation: if 1 maximizes its utility, chooses x^{eq} such that:

- $B'(x^{eq}) = C'(x^{eq})$

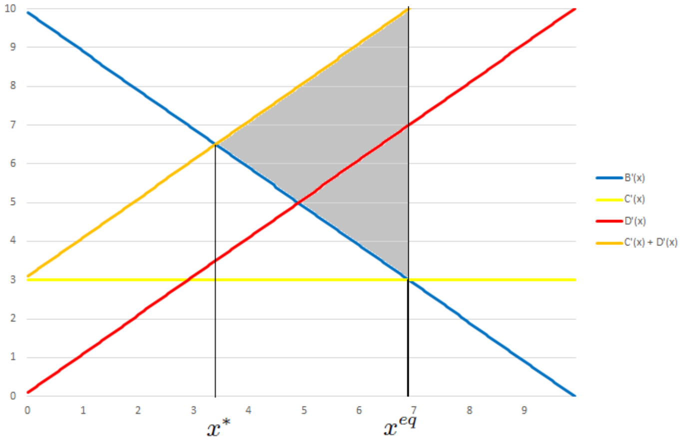
$\rightarrow$ Efficient allocation: chooses x^* such that:

- $B'(x^*) = C'(x^*) + D'(x^*)$

$D'(x)$ represents the discrepancy between the socially optimal and the market equilibrium decisions.

Objective of the policymaker: find a way to set x to x^* instead of x^{eq}.

A graphical example



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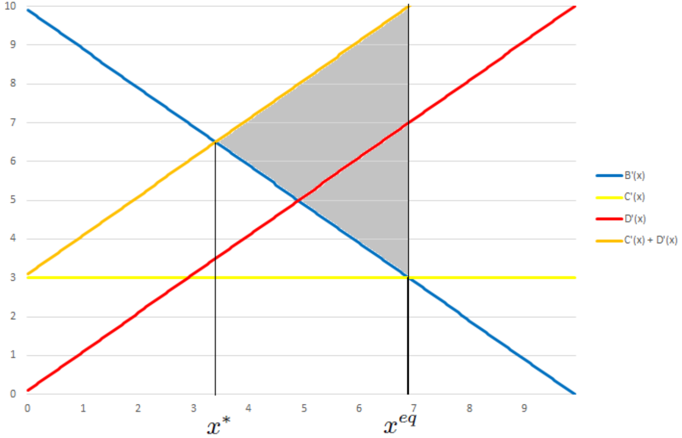

The grey area represents the deadweight loss associated with the externality, *i.e.* the amount of social welfare lost because of it.

Restoring efficiency

To restore efficiency, we need to:

1. determine the value of the external effects that create a discrepancy between private and social marginal costs and benefits;
2. lead agents to change their behavior to account for these external effects. This can be done by:

Restoring efficiency

To restore efficiency, we need to:

1. determine the value of the external effects that create a discrepancy between private and social marginal costs and benefits;
2. lead agents to change their behavior to account for these external effects. This can be done by:
   - forcing agents to consume/produce the “righ” amount;
   - incentivizing them.

$\rightarrow$ These two methods can be used to divide policies into two distinct categories.

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Regulatory "command-and-control" instruments

The regulatory "command-and-control" approach to environmental regulation includes policies meant to reduce pollution through:

- rules imposed on production methods, e.g.:
  - vehicle consumption standards;
  - in Europe, only pesticides approved by the European Commission (after a scientific assessment by the European Food Safety Authority) can be used in agriculture.
- bans on certain products, e.g.:
  - on the use of chlorofluorocarbons following the Montreal Protocol;
  - on the use of leaded fuels (e.g. banned in 1996 in the US);
  - on constructions to protect some coastal areas.
- regulation of their use , e.g.:
  - banning polluting vehicles in certain city centers, or at certain times of the day/week;
  - reglementation on when and where certain pesticides can be used in agriculture.

Economic "market-based" instruments

The economic "market-based" approach to environmental regulation includes instruments meant to provide economic incentives to reduce pollution, such as:

- taxes, e.g.:
    - a carbon tax.
- charges, e.g.:
    - for household waste collection.
- subsidies, e.g.:
    - environmental bonus on less polluting vehicles.
- tradable emission allowances, e.g.:
    - the EU Emissions Trading Scheme.
- economic property rights, e.g.:
    - concessions of natural resources.
- or a combinaition of these, e.g.:
    - deposit-refund systems that combine a tax (deposit) and a subsidy (refund), such as for bottles or batteries;
    - tradable emission allowances with a price floor, such as the UK carbon market.

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→ Within these instruments, we typically distinguish two categories: price vs. quantity regulations. As long as the quantities are tradable, these two approaches are very similar.

Incentives without pollution pricing

In addition, many other policies meant to address climate change that do not strictly fall within these two categories.

In particular, some policies attempt to change behaviors by changing incentives, although not directly pricing pollution. This is for example the case of:

- investments in public goods (e.g. building cycling paths).
- information provision policies (e.g. eco-labels);
- "nudge" types of policies (e.g. voting through your wastes);
- awareness campaigns (e.g. adds on biodiversity loss);
- etc.

→ More on that in lecture 3.b.

A slightly richer example

- Suppose we now have many agents $i = 1, ..., N$.
- Agent i experiences the following utility from the consumption of a polluting good x:

$$U_i(x_i) = B_i(x_i) - C_i(x_i) - D_i(x_1 + ... + x_N).$$

- A utilitarian planner wants to maximize the sum of everyone's welfare. For each i, chooses x_i such that:

$$B_i'(x_i) = C_i'(x_i) - \sum_{j=1}^{N} D_j'(x_1 + ... + x_N)$$

- If agents independently maximize their utility, they choose x_i such that:

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- If agents independently maximize their utility, they choose x_i such that:

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- Thus, agents ignore the externality they cause: $\sum_{j \neq i} D_j'(x_1 + ... + x_N)$, *i.e.* the impact of their pollution on others.
- For simplicity, let's assume damages are the same for everyone, so that $\sum_{j \neq i} D_j'(x_1 + ... + x_N) = (N-1)D'(x_1 + ... + x_N)$

Question: what's the most efficient way to fix this problem?

Solution 1: taxing pollution

Let's assume the government sets a tax τ on the consumption of x. For each agent i, utility becomes:

$$U_i(x_i) = B_i(x_i) - C_i(x_i) - D_i(x_1 + ... + x_N) - \tau x_i.$$

and agents choose x_i such that:

$$B_i'(x_i) = C_i'(x_i) + D_i'(x_1 + ... + x_N) + \tau$$

Simple way to restore efficiency:

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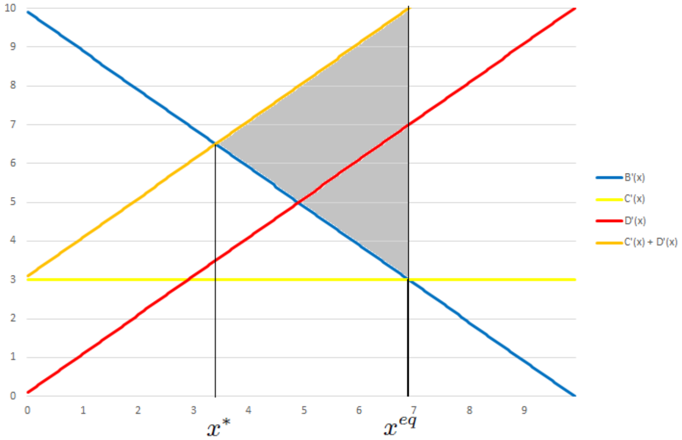
Simple way to restore efficiency: set $\tau = (N-1)D'(x_1 + ... + x_N)$.

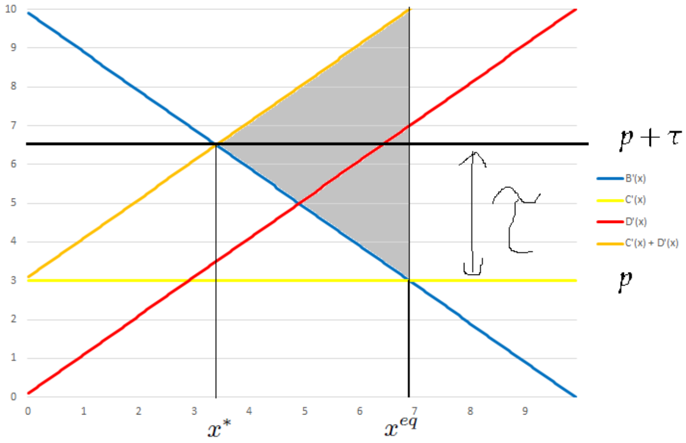
In the context of climate change: to restore efficiency, the carbon tax must be set at the (marginal) social cost of carbon.

Taxing pollution: a graphical example (1/2)

Back to our very simple example. Graphically, how do we represent the tax that restores efficiency?



Taxing pollution: a graphical example (2/2)



The value of τ corresponds to the value of the marginal damage ($D'(x)$, the red curve) evaluated at the optimal allocation (at x^*), *i.e.* $\tau = D'(x^*)$.

Solution 2: subsidizing pollution abatement

Let's assume the government offers a subsidy s when agents accept to reduce their emission below a certain threshold $\bar{x}$. For each agent i, utility becomes:

$$U_i(x_i) = B_i(x_i) - C_i(x_i) - D_i(x_1 + ... + x_N) + s(\bar{x} - x_i).$$

and agents choose x_i such that:

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Simple way to restore efficiency: set $s = (N-1)D'(x_1 + ... + x_N)$.

In terms of efficiency, same as the tax. Main difference is in terms of equity. Instead of making polluters pay for their pollution, the government pays them for reducing it.

Solution 3: tradable pollution permits

Let's assume the government gives to each agent i a pollution permit $\bar{x}_i$. Agents can sell their excess permits or buy additional ones if they want to pollute more. For each agent i, utility becomes:

$$U_i(x_i) = B_i(x_i) - C_i(x_i) - D_i(x_1 + ... + x_N) + p(\bar{x}_i - x_i).$$

and agents choose x_i such that:

$$B_i'(x_i) = C_i'(x_i) + D_i'(x_1 + ... + x_N) + p$$

with:

$$\sum_i x_i \leq \sum_i \bar{x}_i$$

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with:

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Simple way to restore efficiency: set $\sum_i \bar{x}_i = x^*$. What will happen to p then?
$\rightarrow$ At equilibrium, will be equal to the optimal τ, *i.e.* $p = (N-1)D'(x_1 + ... + x_N)$!

Again, price mechanism, very similar to a tax. Instead of setting a tax that leads to the desired quantity (x^*), set the aggregate quantity directly, and let agents trade with each other. **Importantly**, initial allocation of $\{\bar{x}_i\}$ does not matter for efficiency (but it does for equity)!

Solution 4: non-tradable pollution permits

Let's assume the government gives to each agent i a pollution permit $\bar{x}_i$. Agents are not allowed to trade them, and can only pollute that maximum amount. In equilibrium, if $\bar{x}_i < x_i^{eq}$, then all agents consume exactly $\bar{x}_i$.

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To restore efficiency, need to set $\bar{x}_i$ such that:

$$B_i'(x_i) - C_i'(x_i) - D'(x_1 + ... + x_N) = (N-1)D'(x_1 + ... + x_N)$$

Big difference with the previous 3 market based solutions: here, to restore efficiency, need to set one policy per polluter. With many polluters, enormous information cost!

Cost-effectiveness and the market-based approach

In this simple economy, market-based instruments offer the most efficient response to the problem caused by pollution. Indeed,

- by imposing a uniform price on the externality, equalization of the marginal abatement costs of all polluters;
- the emission reductions undertaken will be all those (and only those) requiring an effort lower than the price of the externality (Baumol & Oates, 1971);
- the environmental objective is attained at the lowest possible cost.

→ For this reason, these instruments are called **« cost-effective »**.

Cost-effectiveness and the command-and-control approach

For the same to be true of regulatory instruments, it is necessary to set specific standards for each polluter according to his or her abatement cost:

- when polluters are numerous and heterogeneous, and even more so when there are information asymmetries between polluters and the regulator regarding these costs, such a policy is not feasible;
- the costs of pollution abatement may thus be too high for those who have the greatest difficulty in changing their behavior and too low for others who could have reduced their pollution further.

$\rightarrow$ Since marginal abatement costs are not equalized, it is possible to achieve further reductions of aggregate pollution with an equivalent or lower level of aggregate effort.

Cost-effectiveness: a more concrete example (1/2)

Let's consider a regulator that wants to limit pollution from private vehicles.

- We assume that there are two types of individuals in society:
  - urban individuals driving 5,000km per year with good access to public transports;
  - rural individuals driving 10,000km per year with bad access to public transports.
- After analyzing scientific evidence, it has set a pollution target consistent with each individual driving no more than 5,000km per year.
- Now, imagine the regulator opts for command-and-control regulation and fixes a maximum of 5,000km per year for each individual.

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- Now, imagine the regulator opts for command-and-control regulation and fixes a maximum of 5,000km per year for each individual.

Then, urban people make no effort to reduce their consumption, while rural people have to halve their consumption $\rightarrow$ very inefficient distribution of efforts!

Cost-effectiveness: a more concrete example (2/2)

- The same target could be met at a lower cost if, say, urban people would reduce their consumption to 4,000km and rural people to 6,000km;
- or maybe 3,000km/7,000km, or 1,000km/9,000km: this depends on private abatement costs unknown to the regulator;
- in addition, if people differ within these groups, even more efficient allocations could be attained by transfering the efforts to those for whom it is the least costly.

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- in addition, if people differ within these groups, even more efficient allocations could be attained by transfering the efforts to those for whom it is the least costly.

→ If instead the regulator sets a price per km such that on average people drive 5,000km, an efficient allocation of efforts will emerge as a market equilibrium.

The right level of the tax can be found from trial and error, by adjusting its value to eventually reach the target.

Market-based instruments and dynamic efficiency

From a **dynamic** point of view, the equalisation of marginal abatement costs also implies a better efficiency of market instruments, for example through innovation:

- command-and-control instruments impose a binary framework: a clean technology fixed by a standard is adopted or not;
- market instruments make (in our simple framework) any reduction in emissions profitable: thus, they provide incentives for the development of ever cleaner technologies.

$\rightarrow$ The intuition for dynamic efficiency is the same than for static efficiency: market-based instruments equalize marginal abatement costs across agents and across periods.

Climate policies in a second-best world

- So far we have considered a very simplified benchmark case: an economy whose only market failure was the environmental externality.
  - This framework highlights the powerful mechanisms that flow from economic incentives.
- Still, in practice the climate externality is never the only market failure.
  - The comparative advantages of market-based instruments need to be reconsidered;
  - other market failures may compromise the incentives of market-based mechanisms;
  - the incentives from market based mechanisms may further affect other market failures;
  - obviously, the efficiency of command-and-control policies may also be affected by other market failures.
- Climate change is a global challenge affecting all sectors of the economy:
  - multiple market failures call for multiple instruments, different policies can be complementary.

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- Climate change is a global challenge affecting all sectors of the economy:
  - multiple market failures call for multiple instruments, different policies can be complementary.

$\rightarrow$ Despite strong theoretical mechanisms hinting towards the superiority of market-based measures, empirical work is necessary to compare instruments in different contexts.

Multiple instruments to address multiple market failures: a caveat

Although not one single policy can address all the market failures associated to climate change, one should be careful as:

- the fragmentation of sectoral policies with numerous exemptions generates important differences in abatement costs between countries and between sectors, leaving room for significant opportunities to reduce emissions or their abatement costs;
- sectoral policies targeted towards a restricted set of actors are also more subject to lobbying pressure, creating a downward bias in the stringency of regulation;
- many of such policies are in fact very cost-ineffective (*i.e.* generate very large costs for small environmental benefits);
- many of such policies also reflect compromises between polluters and the regulator, and come on top of existing regulations, leading to a blur about the actual purposes and stringency of these mechanisms;
- to avoid "double taxation", the multiplication of these small measures may also delay the implementation of a more comprehensive policy covering a larger share of emissions.

Table of Contents

Are these theoretical results verified in the data?

- Judging the cost-effectiveness of instruments is difficult.
- Empirically, how do we know that the target could not be achieved at a lower cost?
- Still, with the development of market based instruments, more and more studies examine the cost of policies, allowing for comparisons.

See tutorial 2!