Lecture 2

Theory of externalities

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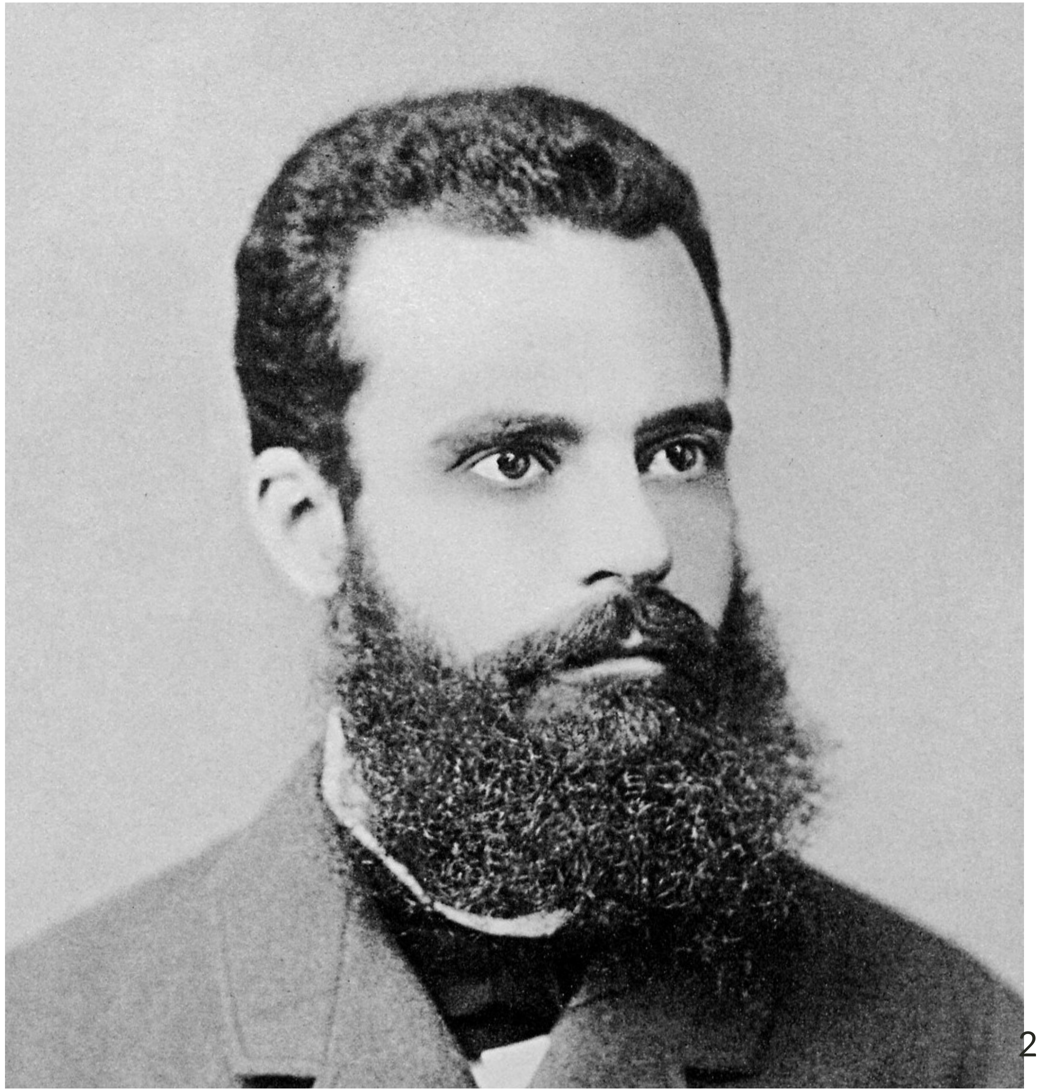
AEM 6510

The welfare-theoretic basis

Before diving into environmental econ we need some definitions

The normative criterion we use to judge the desirability of economic outcomes is called **Pareto optimality**



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Big draw back of Pareto optimality is that some seemingly undesirable outcomes can be Pareto optimal

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First Welfare Theorem: If markets are perfectly competitive and complete, then a decentralized price system will deliver a Pareto optimal allocation

Second Welfare Theorem: If markets are perfectly competitive and complete, then any Pareto optimal allocation can be supported by a decentralized price system and lump sum taxes and transfers

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Why?

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There are not complete markets!

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Pollution, noise, etc

Not changes in wages or prices of regular market goods

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This is the **free rider problem**

Our beginning model

Lets start building our model of the economy

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- Two people

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Our beginning model

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Suppose there is:

- Two people
- A dirty good
- A clean good
- Labor as the only factor (input) of production

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and E is the level of pollution emissions

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Emissions are defined as an *input*, so if you want less emissions you will produce less because $f_E > 0$

We could equivalently define emissions as a joint product but the input setup is cleaner.

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This is all we need for the model, now we just need to set it up, and define two terms

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How do we do this?

By just following the definition of Pareto optimality:

We find the allocations of consumption, labor, and pollution, that maximizes one person's utility while making the other person no worse off than some (arbitrary) benchmark

While also satisfying technology (production) and endowment (labor) constraints

Pareto optimality

The problem is given by:

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z,E} U_1(x_1, z_1, E) \quad \text{subject to:}$$

$$U_2(x_2, z_2, E) \geq \bar{u}_2 \tag{1}$$

$$f(l_x, E) = x_1 + x_2 \tag{2}$$

$$g(l_z) = z_1 + z_2 \tag{3}$$

$$l = l_x + l_z \tag{4}$$

We are maximizing person 1's utility subject to (1) keeping person 2s utility at least some level, (2,3) production constraints, (4) total labor allocation

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Now let's look at the Lagrangian

Pareto optimality

The Lagrangian is given by:

$$\begin{aligned}\mathcal{L} = \max_{x_1, x_2, z_1, z_2, l_x, l_z, E} & U_1(x_1, z_1, E) \\ & + \lambda_u[U_2(x_2, z_2, E) - \bar{u}_2] \\ & + \lambda_x[f(l_x, E) - x_1 - x_2] \\ & + \lambda_z[g(l_z) - z_1 - z_2] \\ & + \lambda_l[l - l_x - l_z]\end{aligned}$$

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Now let's look at the FOCs

Pareto optimality: Problem

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Pareto optimality: Consumption FOCs

$$\frac{\partial U_1}{\partial x_1} = \lambda_x, \qquad \frac{\partial U_1}{\partial z_1} = \lambda_z$$

and

$$\lambda_u \frac{\partial U_2}{\partial x_2} = \lambda_x, \qquad \lambda_u \frac{\partial U_2}{\partial z_2} = \lambda_z$$

Marginal utility equals the shadow price of the good

Pareto optimality: Labor FOCs

$$\lambda_x \frac{\partial f}{\partial l_x} = \lambda_l, \qquad \lambda_z \frac{\partial g}{\partial l_z} = \lambda_l$$

The marginal product of labor equals the shadow price of labor

Pareto optimality: Emissions FOC

$$-\left[\frac{\partial U_1}{\partial E} + \lambda_u \frac{\partial U_2}{\partial E}\right] = \lambda_x \frac{\partial f}{\partial E}$$

The marginal utility cost of emissions equals the marginal product of emissions

Consumption efficiency

The consumption FOCs give us efficiency in consumption:

$$MRS_1^{xz} \equiv \frac{\partial U_1}{\partial x_1} \bigg/ \frac{\partial U_1}{\partial z_1} = \lambda_x / \lambda_z = \frac{\partial U_2}{\partial x_2} \bigg/ \frac{\partial U_2}{\partial z_2} \equiv MRS_2^{xz}$$

Efficiency in consumption requires that the marginal rate of substitution (MRS) between individuals is equal (i.e. the slopes of their indifference curves are equal)

Exchange efficiency

The consumption and labor supply FOCs give us

$$MRS_i^{xz} \equiv \frac{\partial U_i}{\partial x_i} \bigg/ \frac{\partial U_i}{\partial z_i} = \lambda_x / \lambda_z = \frac{\partial g}{\partial l_z} \bigg/ \frac{\partial f}{\partial l_x} \equiv MRT^{xz}$$

MRSs must equal the marginal rate of transformation (MRT)

The slope of the indifference curves must equal the slope of the production possibility frontier

Emissions efficiency

Substitute in the consumption FOCs to obtain a new expression for emissions efficiency:

$$MRS_1^{Ex} + MRS_2^{Ex} \equiv -\frac{\partial U_1}{\partial E} \Big/ \frac{\partial U_1}{\partial x_1} - \frac{\partial U_2}{\partial E} \Big/ \frac{\partial U_2}{\partial x_2} = \frac{\partial f}{\partial E}$$

The marginal product of emissions must equal the sum of the marginal rates of substitution of between x and E across both individuals

General Intuition

We can understand (prove) why these conditions need to be met by considering cases when they are not met

For any case where the three efficiency conditions are not met, we can show there exists a possible **Pareto improvement** $\rightarrow$ the conditions must be met for Pareto optimality

> A Pareto improvement is a reallocation of resources that makes at least one person better off without making anyone else worse off

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If Bob gives Ann 3 units of z in exchange for 1 unit of x, **both are better off**

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Bob was willing to give up 4 units, Ann was willing to accept 2 units $\rightarrow$ both are 1 unit of z better off

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- If we move labor from producing x to z we can get 3 units of z for 1 unit of x

If we give up 1 unit of x, we get 3 units of z $\rightarrow$ the consumer gets 2 more units of z than they needed to be better off

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Suppose MRS_1^{Ex} + $\text{MRS}_2^{Ex} = 3$ and $\frac{\partial f}{\partial E} = 4$, these conditions tell us that:

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- The total cost to both consumers of 1 more unit of E in terms of units of x is 3
- 1 more unit of E gets us 4 more units of x

If we increase E by 1 unit, the benefits (4) outweigh the costs (3), we can make the consumers better off

Competitive markets

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In the free market:

- Consumers take the price of goods as given
- Firms take the price of inputs as given

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Each firm maximizes profit

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The utility maximization problem is:

$$\max_{x_i, z_i} U_i(x_i, z_i, E) \quad \text{subject to: } y_i = p_x x_i + p_z z_i$$

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The Lagrangian is

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with first-order conditions:

$$\frac{\partial U_i}{\partial x_i} = \lambda_i p_x, \qquad \frac{\partial U_i}{\partial z_i} = \lambda_i p_z$$

Competitive markets

The profit maximization problems for firms producing z and x are:

$$\max_{l_z} p_z g(l_z) - w l_z, \qquad \max_{l_x, E} p_x f(l_x, E) - w l_x$$

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This gives us the FOCs for the firm producing x:

$$p_x \frac{\partial f}{\partial l_x} = w \qquad p_x \frac{\partial f}{\partial E} = 0$$

and the firm producing z

$$p_z \frac{\partial g}{\partial l_z} = w$$

Competitive markets: Consumption

The consumption first-order conditions:

$$\frac{\partial U_i}{\partial x_i} = \lambda_i p_x, \qquad \frac{\partial U_i}{\partial z_i} = \lambda_i p_z$$

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The equal MRS condition for efficiency in consumption is met

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The MRS=MRT exchange efficiency condition is met

Competitive markets: Emissions

The efficiency condition for emissions:

$$-\frac{\partial U_1}{\partial E}\Bigg/\frac{\partial U_1}{\partial x_1}-\frac{\partial U_2}{\partial E}\Bigg/\frac{\partial U_2}{\partial x_2}=\frac{\partial f}{\partial E}$$

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is not met!

The free market provides no incentive for the firm to treat E as scarce or to account for its impact on consumers: the firm faces a price on pollution of 0

Market intervention

Much of environmental economics is about designing policy to correct market failures

Market intervention

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Suppose a firm now has to pay a fee τ^* per unit of emissions, can we achieve the optimal outcome?

Emissions taxation

The firm's problem is now:

$$\max_{l_x,E} p_x f(l_x, E) - wl_z - \tau^* E$$

with first-order conditions:

$$p_x \frac{\partial f}{\partial l_x} = w, \qquad p_x \frac{\partial f}{\partial E} = \tau^*$$

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Is there a fee that can satisfy the emissions efficiency condition achieve the Pareto optimal outcome?

Emissions taxation: Conditions

Recall the firm's FOC is:

$$p_x \frac{\partial f}{\partial E} = \tau^*$$

and the emissions efficiency condition is:

$$-\frac{\partial U_1}{\partial E} \bigg/ \frac{\partial U_1}{\partial x_1} - \frac{\partial U_2}{\partial E} \bigg/ \frac{\partial U_2}{\partial x_2} = \frac{\partial f}{\partial E}$$

Emissions taxation: Solution

Notice that if you multiply the right hand side of the emissions efficiency condition by p_x, it is equal to the left hand side of the firm FOC

The Pareto optimal tax is thus:

$$\tau^* = -p_x \left[\frac{\partial U_1}{\partial E} \bigg/ \frac{\partial U_1}{\partial x_1} + \frac{\partial U_2}{\partial E} \bigg/ \frac{\partial U_2}{\partial x_2} \right]$$

This tax can thus make the firm's profit-maximizing condition consistent with Pareto optimality

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The tax is the marginal utility cost of emissions in dollar terms

Emissions taxation

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The tax depends on marginal utility of consumption, this implies two things:

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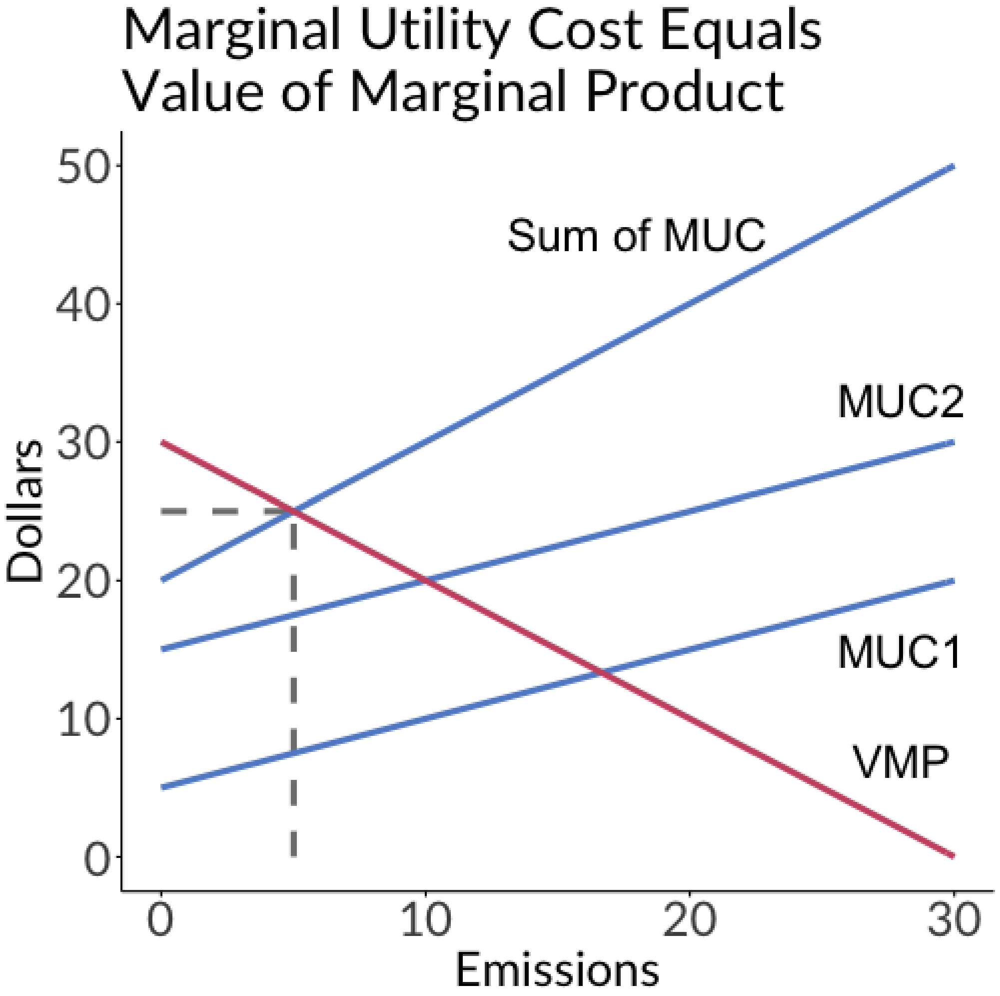
Changes in income or factor endowments will therefore change the level of the Pareto optimal tax!

Graphical emissions taxation



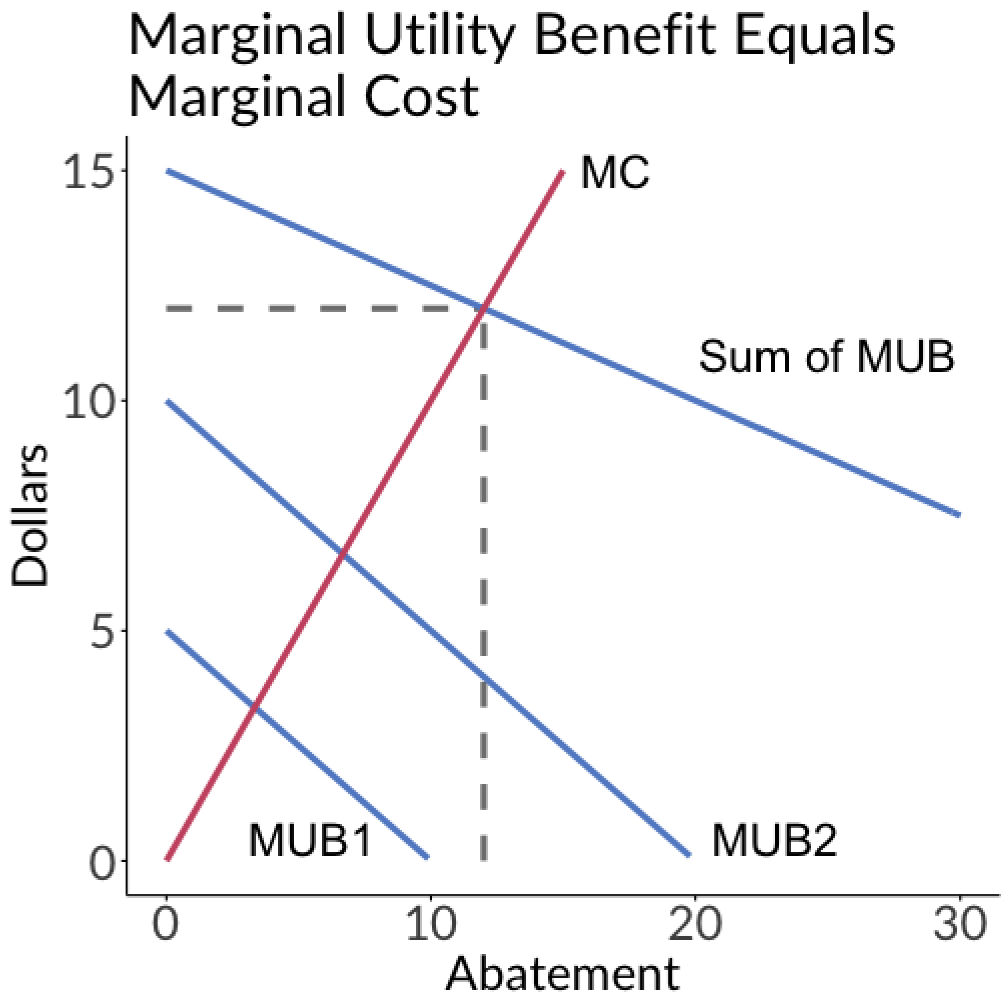
$-p_x \left[\frac{\partial U_i}{\partial E} \bigg/ \frac{\partial U_i}{\partial x_i} \right]$ is the individual marginal utility cost of emissions

$p_x \frac{\partial f}{\partial E}$ is the value of marginal product of emissions (VMP)

At a Pareto optimum the sum of MUCs must be equal to the VMP

MC of emissions must equal MB

Graphical emissions taxation: abatement



Let abatement A^* be how much we reduce emissions below baseline: $A^* = \bar{E} - E^*$

$-p_x \left[\frac{\partial U_i}{\partial E} \middle/ \frac{\partial U_i}{\partial x_i} \right]$ is the individual marginal utility benefit

$p_x \frac{\partial f}{\partial E}$ is the marginal cost of abatement