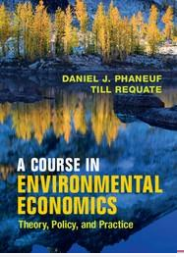


Environmental Economics

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Kiel University

PhD Course at Oslo University
April 2022

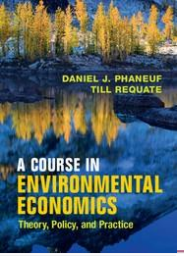


This material of this course is based on material from the book:

A Course in Environmental Economics: Theory, Policy and Practice

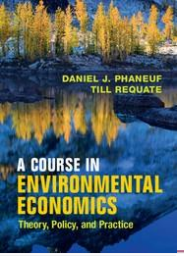
by Daniel Phaneuf and Till Requate,

Cambridge University Press 2017
First Edition



Chapter 1

Environmental Economics and the Theory of Externalities

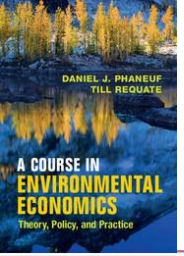


Environmental Economics

- Environmental Economics falls under the rubric of **welfare economics** and the **theory of externalities**, dealing specifically with a particular type of market failure.

- One person´s interactions with the environment can have direct and unsolicited effects on another person.

- Two aspects of studying economics:
  - Positive economics: describing what is the case.
  - Normative economics: describing what ought to be.



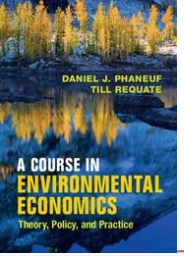
Environmental Economics

Different types of market failure:

- Market power: monopoly, oligopoly, imperfect competition (in general terms) -> antitrust policy
- Externalities
  - Positive externalities: vaccination, bee keeping, education!, R&D, other public goods
  - **Negative externalities**, not clearly defines property rights
- Asymmetric information, especially about the quality of goods
- Coordination failure

- Inequality, distributional issues ?

- Transaction cost?
- Inequality of supply and demand?

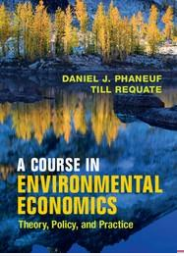


Environmental Economics

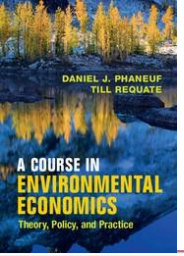
- Environmental Economics deals mainly with negative externalities through pollution, and the destruction of environmental goods (e.g. landscape degradation)

- Main topics of Environmental Economics:
  - Environmental policy tools:
    - How do they work? Comparative statics effects
    - Design of efficient environmental policy
    - Second-best analysis (optimizing policy under constraints)

  - Valuation methods to provide environmental goods (not addressed in this course)



1.1 Markets, Welfare, and Market Failure



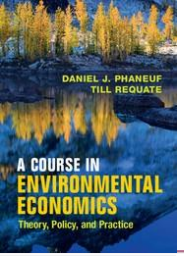
1.1 Markets, Welfare, and Market Failure

- **Definition** 1.1: **Pareto optimality**
  An economic outcome is said to be Pareto optimal if a reallocation of resources cannot make at least one person better off without making another person worse off.

- From this it follows that there is the potential for Pareto improvement if one person´s well-being can be improved without compromising the well-being of another person.

- A virtue of the criterion is that there is no need for income judgements.

- Pareto optimality thus sidesteps the problematic issue of equity and fairness among economic agents, focusing instead on efficiency.

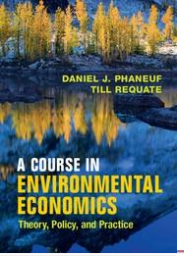


1.1 Markets, Welfare, and Market Failure

- The **first welfare theorem** states that if markets are *complete* and *perfectly competitive*, a decentralized price system coupled with self-interested behavior provides an allocation of resources among society´s individuals that is Pareto optimal.

- The **second welfare theorem** states the converse of this. If markets are complete and perfectly competitive, any Pareto optimal allocation can be supported by a price system arising from an appropriate redistribution of income.

- The appeal of the welfare theorems is obvious: if the conditions are met, ***society can achieve the largest pie (efficiency) simply be allowing the free market to function***.



1.1.1 An example of a toy economy

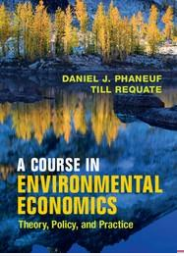
Consider a toy economy with

- two individuals 1 and 2,
- two consumption goods *X* and *Z*,
- Two firms producing good *X* and *Z* with labor *L* as the only factor of production.

- Utility function by agent *i=1,2*: $U_i(x_i, z_i)$.
- where x_i and z_i denote consumption levels.

- Production functions:
  - $x = f(l_x)$.
  - $z = g(l_z)$.

- Labor is constrained by work time endowment: $l_x + l_z = l = l_1 + l_2$, where l_i = labor supply of consumer *i*.
- So for simplicity, the supply of labor is inelastic, and there is no disutility of labor to consumers.

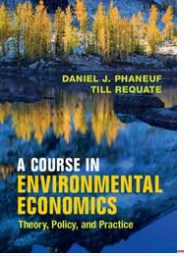


1.1.1 An example of a toy economy

- We want to characterize a **Pareto optimal allocation** of resources in this economy.

- This involves finding the **consumption levels** and **factor allocations** that maximizes one person´s utility in a way that makes the other persons no worse off than a given benchmark.

- For this purpose, we maximize person 1´s utility subject to the constraint that person 2 obtains at least some utility level $\bar{u}_2$, that production satisfies the needs of both persons, and both persons work for the representative firms.



1.1.1 An example of a toy economy

Formally:

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z} U_1(x_1,z_1)$$

subject to the contraints:

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

$$f(l_x) = x_1 + x_2$$

$$g(l_z) = z_1 + z_2$$

$$l = l_x + l_z$$

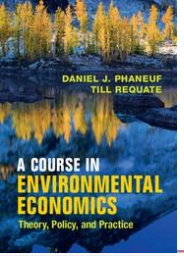
Note that we can choose any feasible utility level for person 2 here.

By this, we find all Pareto-optimal allocations!

To solve this, we set up the Lagrange function:

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z} U_1(x_1,z_1) + \lambda_u\left[U_2(x_2,z_2) - \bar{u}_2\right] + \lambda_x\left[f(l_x) - x_1 - x_2\right] \qquad (0.1)$$

$$+\lambda_z\left[g(l_z) - z_1 - z_2\right] + \lambda_1\left[l - l_x - l_z\right],$$



1.1.1 An example of a toy economy

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z} U_1(x_1,z_1)+\lambda_u\left[U_2(x_2,z_2)-\bar{u}_2\right]+\lambda_x\left[f(l_x)-x_1-x_2\right] \qquad (0.1)$$
$$+\lambda_z\left[g(l_z)-z_1-z_2\right]+\lambda_1\left[l-l_x-l_z\right],$$

- Beginning with the consumption levels we have:

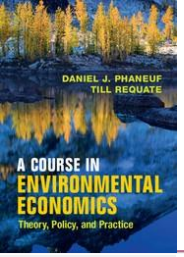
$$\frac{\partial U_1(\bullet)}{\partial x_1}=\lambda_x, \qquad \frac{\partial U_1(\bullet)}{\partial z_1}=\lambda_z \qquad (0.2)$$

$$\lambda_u\frac{\partial U_2(\bullet)}{\partial x_2}=\lambda_x, \qquad \lambda_u\frac{\partial U_2(\bullet)}{\partial z_2}=\lambda_z \qquad (0.3)$$

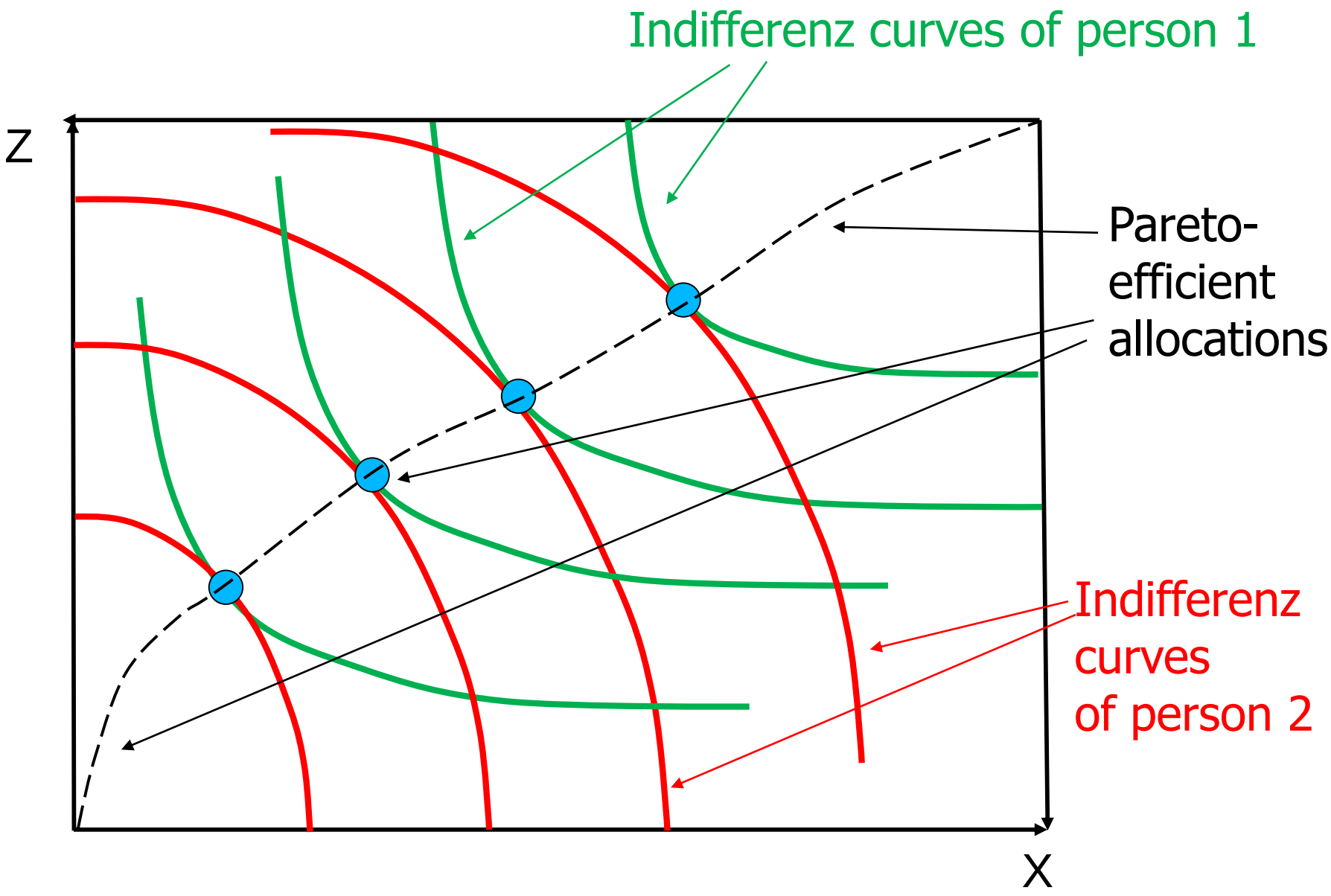
- We can derive the expression for **efficiency in consumption**:

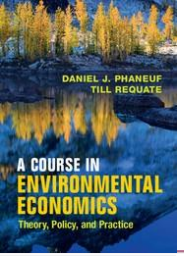
$$MRS^1_{x,z}=\frac{\partial U_1(\bullet)/\partial x_1}{\partial U_1(\bullet)/\partial z_1}=\frac{\lambda_x}{\lambda_z}=\frac{\partial U_2(\bullet)/\partial x_2}{\partial U_2(\bullet)/\partial z_2}=MRS^2_{x,z} \qquad (0.4)$$

Thus: efficiency in consumption requires that the marginal rates of substitution between goods are equal for both individuals!



Pareto Optimality in the Edgeworth Box





1.1.2 Pareto Optimality

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z} U_1(x_1,z_1)+\lambda_u\left[U_2(x_2,z_2)-\bar{u}_2\right]+\lambda_x\left[f(l_x)-x_1-x_2\right] \qquad (0.1)$$
$$+\lambda_z\left[g(l_z)-z_1-z_2\right]+\lambda_1\left[l-l_x-l_z\right],$$

- Taking derivatives with respect to **labor** we obtain:

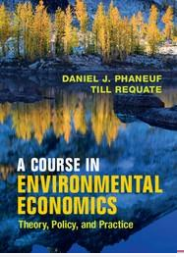
$$\lambda_x\frac{\partial f(\cdot)}{\partial l_x}=\lambda_l, \qquad \lambda_z\frac{\partial g(\cdot)}{\partial l_z}=\lambda_l, \qquad (0.2)$$

- Efficiency in production requires that the shadow value of the marginal product of labor is equal to the shadow price of labor.

- We gain the efficiency in exchange:

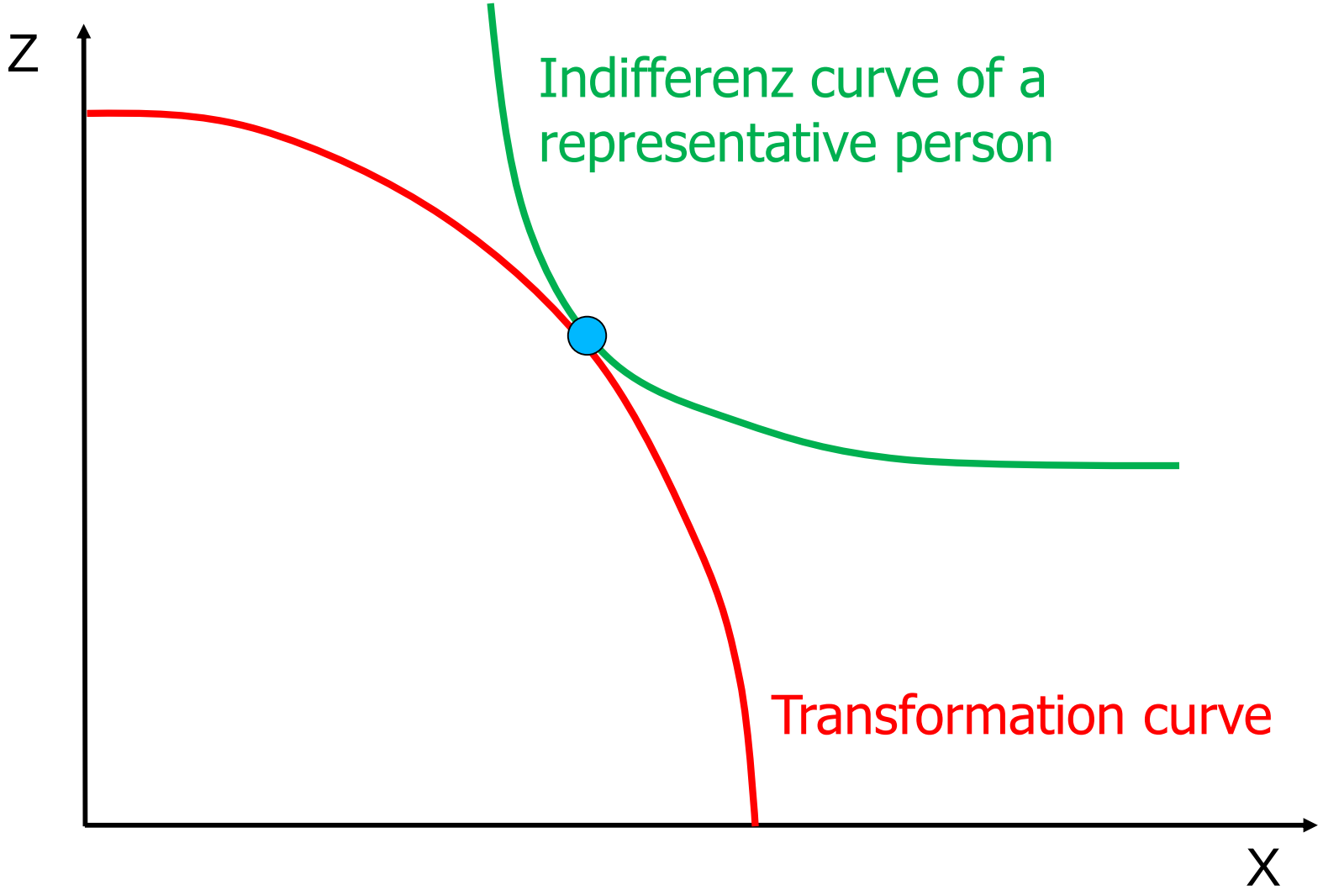
$$MRS^i_{x,z}\frac{\partial U_i(\bullet)/\partial x_i}{\partial U_i(\bullet)/\partial z_i}=\frac{\lambda_x}{\lambda_z}=\frac{\partial g(\bullet)/\partial l_z}{\partial f(\bullet)/\partial l_x}=MRT_{x,z} \qquad (0.3)$$

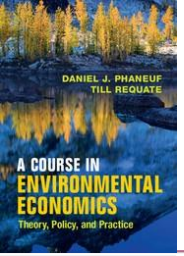
- **Pareto optimality**: The marginal rates of substitutions are equal to the marginal rate of transformation between *X* and *Z*.



Pareto optimality with production (transformation curve)

Or: the slope of the production possibility curve is equal to the slope of each person´s indifference curve.





1.1.3 The Competitive Market

- We now ask if the free market outcome meets the Pareto criteria when the output and factor markets are competitive.

- Acting as price-takers, the individuals maximize utility and the firms maximize profits.

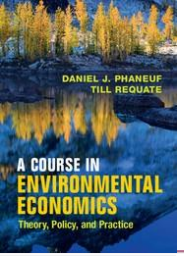
- The utility maximization problem for each person i is:

$$\max_{x_i, z_i} U_i(x_i, z_i) + \lambda_i \left[y_i - p_x x_i - p_z z_i \right] \qquad (0.4)$$

- where p_x and p_z are the prices for good X and Z and
- y_i is income from the fixed supply of labor $w \cdot l_i$
- We get for the F.O.C.s:

$$\frac{\partial U_i(x_i, z_i)}{\partial x_i} = \lambda_i p_x \qquad (0.5)$$

$$\frac{\partial U_i(x_i, z_i)}{\partial z_i} = \lambda_i p_z \qquad (0.6)$$

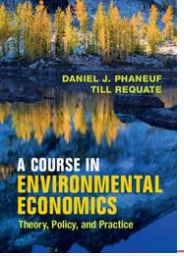


1.1.3 The Competitive Market

- Dividing the two equations by each other, we obtain the condition for efficiency in consumption:

$$\frac{\partial U_1(\bullet)/\partial x_1}{\partial U_1(\bullet)/\partial z_1} = \frac{p_x}{p_z} = \frac{\partial U_2(\bullet)/\partial x_2}{\partial U_2(\bullet)/\partial z_2} \qquad (0.7)$$

- We see: the MRS's are equal across consumers, i.e. consumption is allocated efficiently.



1.1.3 The Competitive Market

- For **the firms** the **profit maximization** problems are:

$$\max_{l_x}\left\{p_x f\left(l_x\right)-wl_x\right\}$$
$$\max_{l_z}\left\{p_z g\left(l_z\right)-wl_z\right\}$$

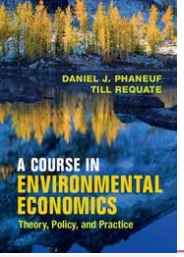
- where *w* is the wage rate.

- The f.o.c. for profit maxima are then:

$$p_x \frac{\partial f\left(\bullet\right)}{\partial l_x}=w \qquad (0.8)$$
$$p_z \frac{\partial g\left(\bullet\right)}{\partial l_z}=w \qquad (0.9)$$

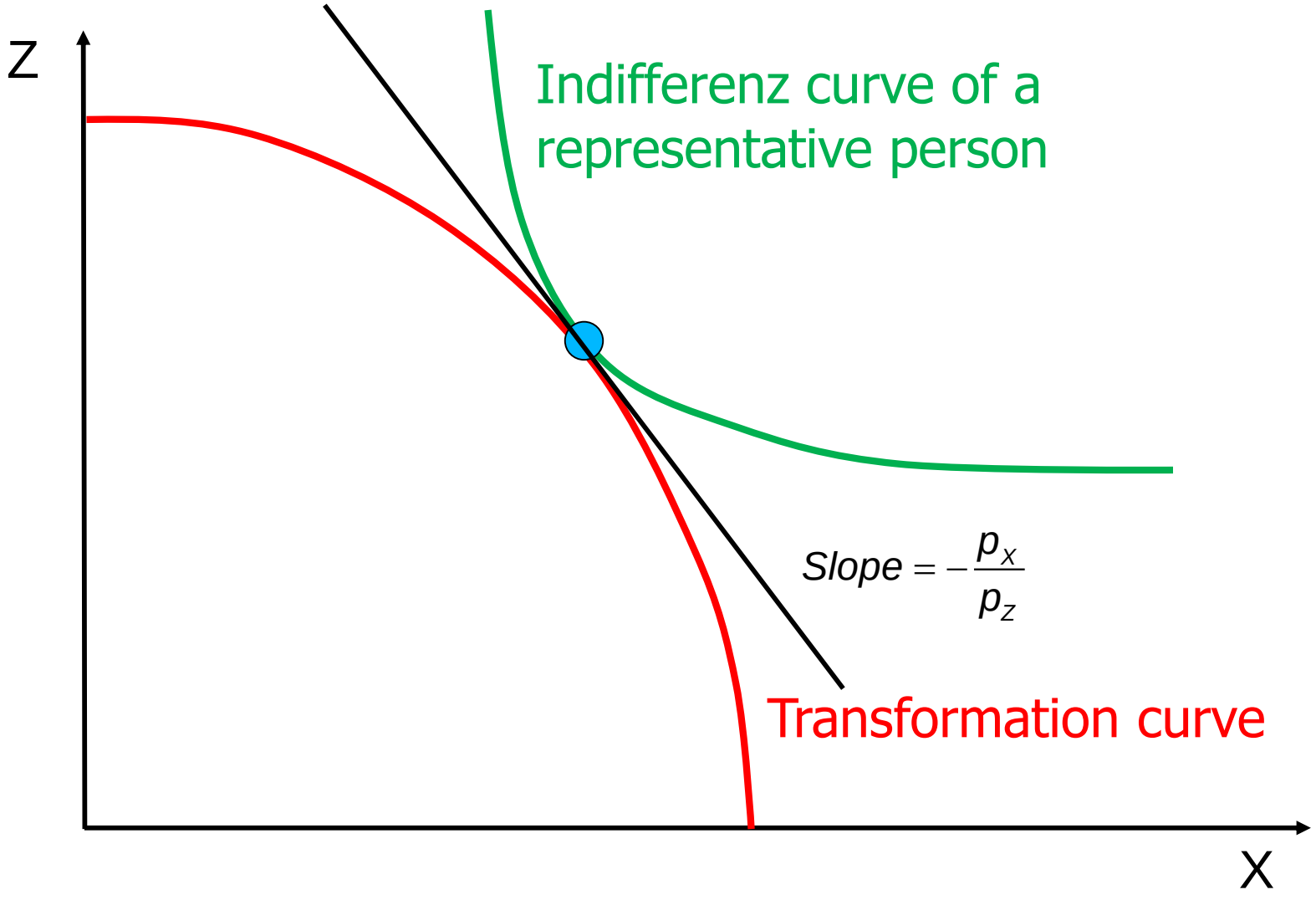
- This implies

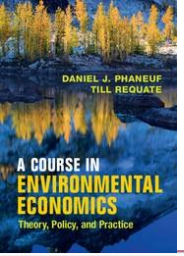
$$\frac{p_x}{p_z}=\frac{\frac{\partial g\left(\bullet\right)}{\partial l_z}}{\frac{\partial f\left(\bullet\right)}{\partial l_x}} \qquad (0.10)$$



Pareto optimality with production (transformation curve)

Decentralization through prices





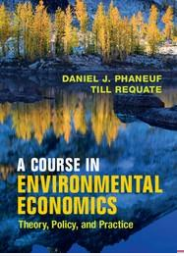
1.1.3 The Competitive Market

We see that (0.7) and (0.10) imply the condition for Pareto-optimality (0.3).

In other words, the allocation arising in a competitive (!) market is always Pareto-efficient.

There is no market failure, except maybe for distributional issues.

This will be different if there are externalities from production.



1.1. Markets, Welfare, and Market Failure

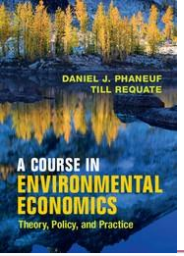
- For environmental problems, **complete markets** are the exception rather than the rule, owing to the related problems and public goods.

- **Definition** 1.2: **Externality**

  An externality exists when Agent A´s utility or production depends directly on real variables (actions) chosen by another agent B, without an offer of compensation or other attention given to the effect on A´s well-being.

- Many externalities in environmental economics have a structure that is similar to that of public goods.

- Thus public goods, like externalities, lead to a type of missing market situation that violates the conditions of the two welfare theorems.



1.2 Descriptive Explanation of Market Failure

Externalities are existent everywhere in daily life.

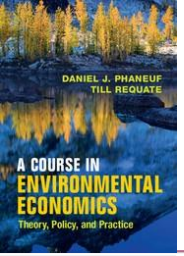
Externalities can be negative or positive.

Examples for negative externalities:

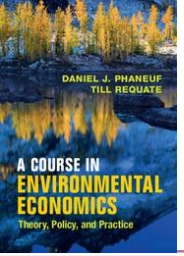
- Air pollution by cars and factories – negative health effects
- Water pollution by factories, agriculture -> negative health effects
- Nuclear waste
- Infection of other persons by an infectious disease (COVID19),
- In particular, refusing vaccination causes an externalities.
- (Over-) exploitation of an Allmende (i.e. open access) resource

Examples for positive externalities:

- Learning spillovers, notably among children
- R&D spill-overs
- National defense expenditures by a friendly country.



1.3 A formal model of externalities



1.3 A formal model of externalities

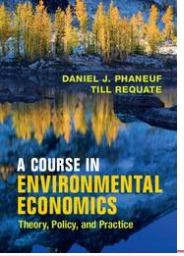
- We now extend our toy economy with two individuals, two goods and labor as the only factor of production.

- But now good *X* is a dirty good and good *Z* a clean good.

- The dirtiness comes from a polluting input:
- Production function for the X-good: $x = f(l_x, E)$, where E is the amount of the polluting input (for simplicity) = level of the pollution emissions.

- Consumers suffer from the pollution,
- Utility function by agent *i*: $U_i(x_i, z_i, E)$, where again x_i and z_i are consumption levels. E is the level of the pollution.

- Note that both consumers suffer from the same amount *E*. Therefore the pollution is a *public bad.*



1.3 A formal model of externalities

- The clean good Z is produced using only labor: $z = g(l_z)$.
- Labor is constrained by work time endowment: $l_x + l_z = l$.
- To find a Pareto-optimal allocation we proceed as before:

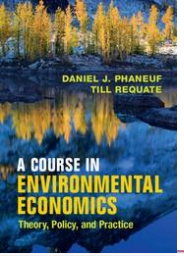
$$\max_{x_1,x_2,z_1,z_2,l_x,l_z,E} U_1(x_1,z_1,E)$$

subject to the constraints:

$$U_2(x_2,z_2,E) \geq \bar{u}_2$$
$$f(l_x,E) = x_1 + x_2$$
$$g(l_z) = z_1 + z_2$$
$$l = l_x + l_z$$

Lagrangian:

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z,E} U_1(x_1,z_1,E) + \lambda_u\left[U_2(x_2,z_2,E) - \bar{u}_2\right] + \lambda_x\left[f(l_x,E) - x_1 - x_2\right] \quad (1.1)$$
$$+\lambda_z\left[g(l_z) - z_1 - z_2\right] + \lambda_1\left[l - l_x - l_z\right],$$



1.3.1 Pareto Optimality

- Again we derive the F.O.C. for maximization in stages.
- Beginning with the consumption levels we have:

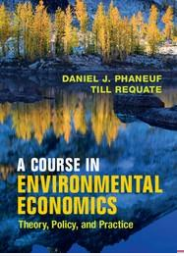
$$\frac{\partial U_1(\bullet)}{\partial x_1} = \lambda_x, \qquad \frac{\partial U_1(\bullet)}{\partial z_1} = \lambda_z \tag{1.2}$$

$$\lambda_u \frac{\partial U_2(\bullet)}{\partial x_2} = \lambda_x, \qquad \lambda_u \frac{\partial U_2(\bullet)}{\partial z_2} = \lambda_z \tag{1.3}$$

- We can derive the expression for **efficiency in consumption**:

$$\frac{\partial U_1(\bullet)/\partial x_1}{\partial U_1(\bullet)/\partial z_1} = \frac{\lambda_x}{\lambda_z} = \frac{\partial U_2(\bullet)/\partial x_2}{\partial U_2(\bullet)/\partial z_2} \tag{1.4}$$

Thus: efficiency in consumption requires that the marginal rate of substitution between goods is equal for both individuals.



1.3.1 Pareto Optimality

$$\max_{x_1,x_2,z_1,z_2,l_x,l_z,E} U_1(x_1,z_1,E)+\lambda_u\left[U_2(x_2,z_2,E)-\bar{u}_2\right]+\lambda_x\left[f(l_x,E)-x_1-x_2\right] \qquad (1.1)$$
$$+\lambda_z\left[g(l_z)-z_1-z_2\right]+\lambda_1\left[l-l_x-l_z\right],$$

- Taking derivatives with respect to labor we obtain:

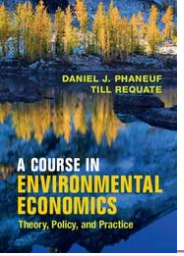
$$\lambda_x\frac{\partial f(\cdot)}{\partial l_x}=\lambda_l, \qquad \lambda_z\frac{\partial g(\cdot)}{\partial l_z}=\lambda_l, \qquad (1.5)$$

- Efficiency in production requires that the shadow value of the marginal product of labor is equal to the shadow price of labor.

- We gain the efficiency in exchange:

$$\frac{\partial U_i(\bullet)/\partial x_i}{\partial U_i(\bullet)/\partial z_i}=\frac{\lambda_x}{\lambda_z}=\frac{\partial g(\bullet)/\partial l_z}{\partial f(\bullet)/\partial l_x} \qquad (1.6)$$

- Pareto optimality: the slope of the production possibility curve is equal to the slope of each person´s indifference curve.



1.3.1 Pareto Optimality

- We complete the Pareto optimal characterization by analyzing the F.O.C. with respect to emissions:

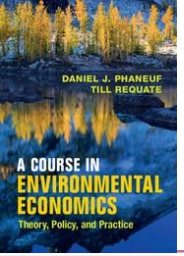
$$\frac{\partial U_1(\bullet)}{\partial E} + \lambda_u \frac{\partial U_2(\bullet)}{\partial E} + \lambda_x \frac{\partial f(\bullet)}{\partial E} = 0 \qquad (1.7)$$

- Now we divide the equation by λ_x , bring $\partial f / \partial E$ on the RHS:

$$\frac{\frac{\partial U_1(\bullet)}{\partial E}}{\lambda_x} + \frac{\lambda_u \frac{\partial U_2(\bullet)}{\partial E}}{\lambda_x} = -\frac{\partial f(\bullet)}{\partial E} \qquad (1.7')$$

- Now use $\partial U_1 / \partial x_1 = \lambda_x$ from (1.2) and $\lambda_u \partial U_2 / \partial x_2 = \lambda_x$ from (1.3) wet

$$-\frac{\partial U_1(\bullet)/\partial E}{\partial U_1(\bullet)/\partial x_1} - \frac{\partial U_2(\bullet)/\partial E}{\partial U_2(\bullet)/\partial x_2} = \frac{\partial f(\bullet)}{\partial E} \qquad (1.8)$$



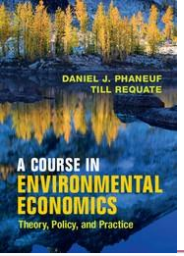
1.3.1 Pareto Optimality

- Once again:

$$-\frac{\partial U_1(\bullet)/\partial E}{\partial U_1(\bullet)/\partial x_1}-\frac{\partial U_2(\bullet)/\partial E}{\partial U_2(\bullet)/\partial x_2}=\frac{\partial f(\bullet)}{\partial E} \qquad (1.8)$$

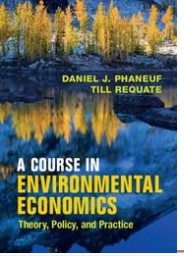
- The LHS is the sum of the marginal rates of substitution between better environment (i.e. less emissions) and the dirty good.
- This sum can also be interpreted as the total (=sum of) the **willingness to pay for pollution reduction** in terms of less consumption of the dirty good.

- The RHS is the **marginal product of the emission** intensive input, but can also be interpreted as the **marginal abatement cost** (i.e. the physical cost in x of reducing E).



1.3.1 Pareto Optimality

- In other words: The optimum emission level should balance the utility cost of emission against the utility benefit of x.
- A reduction in E has the characteristics of a public good.
- Since a reduction in E benefits both people, the marginal cost in x of a reduction in E needs to be compared to the sum of both people´s marginal willingness to give up x to have the reduction.
- When the marginal cost is equal to the marginal willingness to pay for reduced E, the outcome is efficient.



1.3.2 The Competitive Market

- We now ask if the free market outcome meets the Pareto criteria, when the output and factor markets are competitive.
- Acting as price-takers, the individuals maximize utility and the firms maximize profits.
- The utility maximization problem for each person i is:

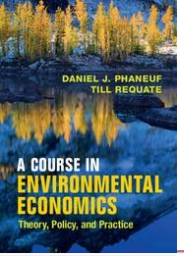
$$\max_{x_i, z_i} U_i(x_i, z_i, E) + \lambda_i \left[y_i - p_x x_i - p_z z_i \right] \tag{1.9}$$

- And we get for the F.O.C.s:

$$\frac{\partial U_i(x_i, z_i, E)}{\partial x_i} = \lambda_i p_x$$

$$\frac{\partial U_i(x_i, z_i, E)}{\partial z_i} = \lambda_i p_z \tag{1.10}$$

- where p_x and p_z are the prices for good X and Z.



1.3.2 The Competitive Market

- We gain the condition for efficiency in consumption:

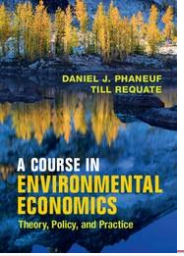
$$\frac{\partial U_1(\bullet)/\partial x_1}{\partial U_1(\bullet)/\partial z_1} = \frac{p_x}{p_z} = \frac{\partial U_2(\bullet)/\partial x_2}{\partial U_2(\bullet)/\partial z_2} \qquad (1.11)$$

- The profit maximization problem for firm z is:

$$\max_{l_z} \left\{ p_z g(l_z) - w l_z \right\} \qquad (1.12)$$

where w is the wage rate.

- This leads to the F.O.C.: $p_z \partial g(\cdot)/\partial l_z = w$.



1.3.2 The Competitive Market

- In the market situation, the firm selects both its labor and emission inputs to maximize profit, treating emissions as a free factor of production.

- The profit maximization problem is:

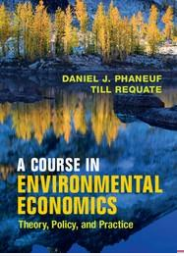
$$\max_{l_x,E}\left\{p_x f\left(l_x,E\right)-wl_x\right\} \tag{1.13}$$

- And for the F.O.C. we gain:

$$p_x\frac{\partial f\left(\bullet\right)}{\partial l_x}=w$$

$$p_x\frac{\partial f\left(\bullet\right)}{\partial E}=0 \tag{1.14}$$

- The condition for an efficient allocation of emissions is not met.
- The unregulated free market provides no mechanism that encourages the firm to account for the impact of its choice on consumers.



1.3.3 Market Intervention

- Arthur Cecil Pigou suggested that if the government can correctly compute and impose a fee which the polluting firm must pay for each unit of emissions, decentralized market behavior will lead to the Pareto optimal result.

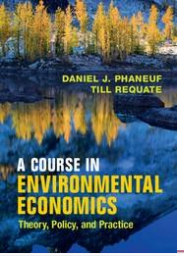
- Thus define the tax rate for emissions τ^* as

$$\tau^* = -p_x \left[\frac{\partial U_1(\bullet)/\partial E}{\partial U_1(\bullet)/\partial x_1} + \frac{\partial U_2(\bullet)/\partial E}{\partial U_2(\bullet)/\partial x_2} \right] \tag{1.15}$$

- Suppose firm x is required to pay τ^* for each unit of pollution emitted.

- The firm´s modified objective function is now:

$$\max_{L_x, E} \left\{ p_x f(I_x, E) - w I_x - \tau^* E \right\} \tag{1.16}$$



1.3.3 Market Intervention

- The F.O.C.s for profit maximum are:

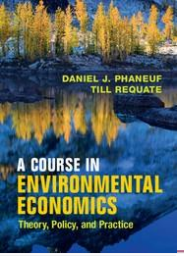
$$p_x \frac{\partial f(\bullet)}{\partial l_x} = w$$

$$p_x \frac{\partial f(\bullet)}{\partial E} = \tau^* = -p_x \left[\frac{\partial U_1(\bullet)/\partial E}{\partial U_1(\bullet)/\partial x_1} + \frac{\partial U_2(\bullet)/\partial E}{\partial U_2(\bullet)/\partial x_2} \right] \qquad (1.17)$$

- Comparing conditions (1.8) to (1.17), we see that the market outcome conditions do indeed match the Pareto optimum conditions when pollution is priced at τ^*.

- This suggests that the government can, in principle, intervene in the market to provide the proper incentive for polluting firms to internalize the externality.

- Note: the tax rate τ^* may change with the initial endowments (income distribution) of the two consumers!



1.3.3 Market Intervention

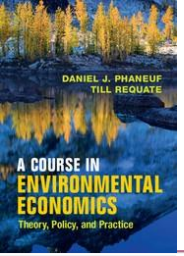
- We can visualize the optimal allocation in two ways:
- In terms of **emissions** and in terms of **abated emissions**.
  - Emissions are a public bad
  - Abated emissions are a public good
- Denote by $$MUC1_E = -p_x \frac{\partial U_1(x_1, z_1, E)/\partial E}{\partial U_1(x_1, z_1, E)/\partial x_1}$$

$$MUC2_E = -p_x \frac{\partial U_2(x_2, z_2, E)/\partial E}{\partial U_2(x_2, z_2, E)/\partial x_2}$$

the "*marginal utility cost" (or marginal disutility) of pollution.*

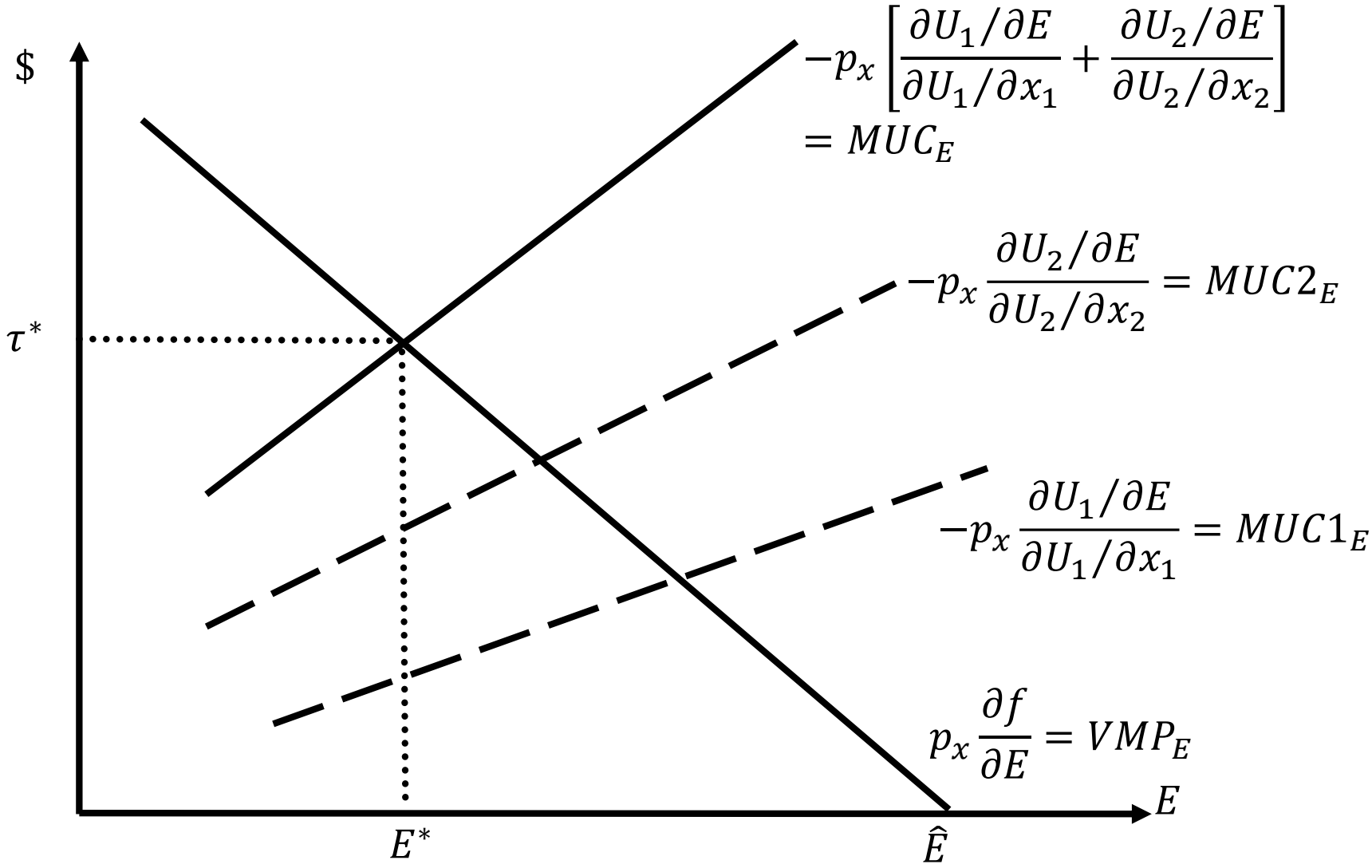
The **value of marginal product** of the polluting input VMP:

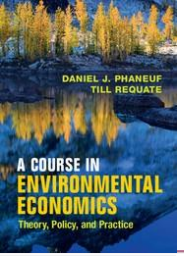
$$VMP_E = p_x \frac{\partial f(I_x, E)}{\partial E}$$



1.3.3 Market Intervention

Figure 1.1, Panel A: Efficient Pollution Level and Pigouvian Tax





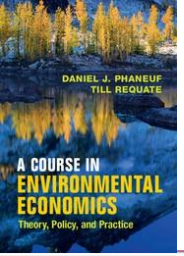
1.3.3 Market Intervention

- We can also illustrated it in terms of abated emissions.
- Denote by

$$MUB1_E = -p_x \frac{\partial U_1(x_1, z_1, E)/\partial E}{\partial U_1(x_1, z_1, E)/\partial x_1}$$

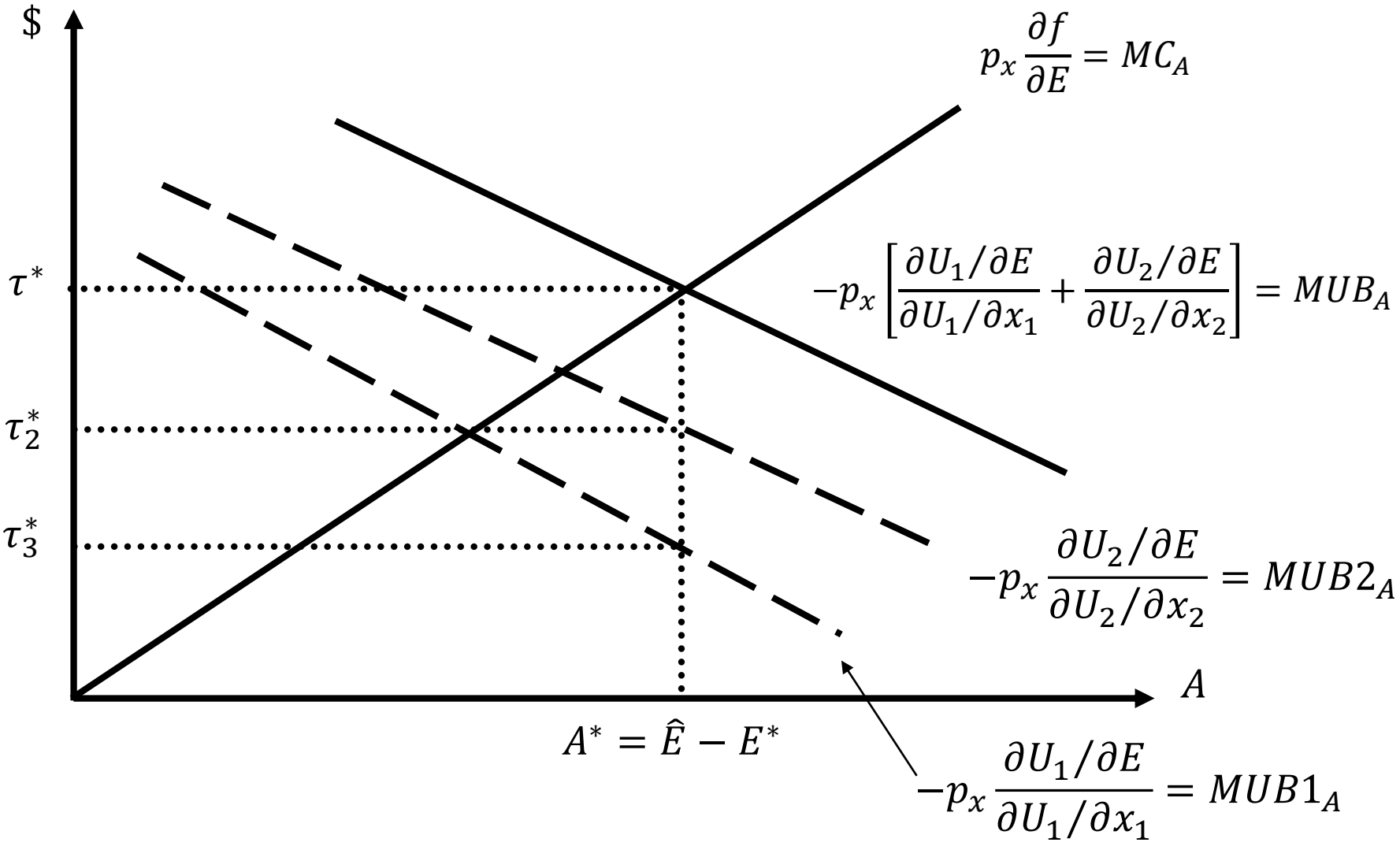
$$MUB2_E = -p_x \frac{\partial U_2(x_2, z_2, E)/\partial E}{\partial U_2(x_2, z_2, E)/\partial x_2}$$

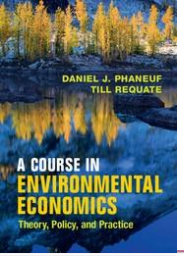
the "*marginal utility benefit" of abatement.*



1.3.3 Market Intervention

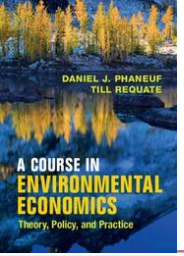
Figure 1.1, Panel B: Efficient Pollution Level and Pigouvian Tax





Summary

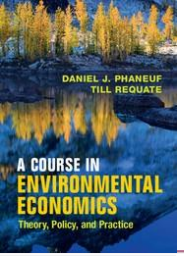
- Neoclassical welfare theory begins by defining a weak normative criterion, Pareto optimality (or Pareto efficiency), which lies at the heart of welfare economics.
- Unregulated polluting behavior is a classic example of an externality.
- The cleanup of pollution, to the extent that it is non-excludable, shares many characteristics with public goods.
- The field of environmental economics is about identifying when environmental market failures exist, studying the properties of different intervention options, and estimating the specific functions that are needed for policy implementation.



Summary

- The most important rule for internalizing an externality is the **Lindahl-Samuelson rule**:

- **The sum of the marginal rates of substitution between pullution reduction (the public good) and the private „dirty“ good needs to be equal to the marginal cost of abating emissions.**



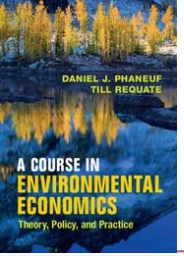
2 Major Pollutants and Pollution Problems

- Pollution types can be physically categorized based on the affected
  - media (water, air, land),
  - the sectors responsible (industry, agriculture, private households, traffic)
  - and the source type (point and non-point).

- Point source type: source of specific emissions can be identified (i.e. a smokestack)

- Non-point source type: sources difficult to identify (agriculture)

- Possible channels on how humans are impacted:
  - health,
  - productivity,
  - amenity,
  - and preservation consequences.



2.1 Water Pollution

- Water pollution is a broad notion that includes the degradation of freshwater surface waters, groundwater, and oceans and coastal areas.

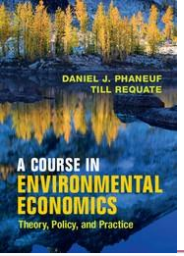
- Common surface water problems are:

a) Organic pollutants that may contain disease-causing bacteria;

b) Excess loading of nutrients;

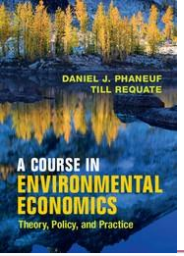
c) Heavy metals;

d) Non-organic solids and sediments from construction sites and agricultural erosion.



2.1 Water Pollution

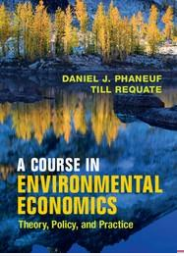
- Groundwater problems occur when fertilizers, pesticides, and chemicals leach into underground.
- Groundwater can also be contaminated by hazardous chemicals – both from natural occurrence and leaching from mining and manufacturing.
- The physical effects of water pollution are as varied as its sources.
- In developed countries many of the impacts flow through amenity and preservation channels.
- The situation in developing countries is almost completely reversed: Access to safe drinking water is limited.



2.2 Air Pollution

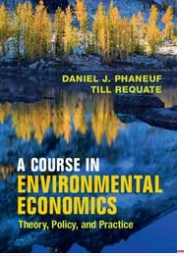
- Air pollution can be roughly grouped into three categorizes:
  - Hazardous (e.g. *CO*, dioxin)
  - conventional (see below)
  - and climate changing (CO_2, methane)

- The primary conventional pollutants include gasses such as:
  - sulfur dioxide (SO_2),
  - nitrogen oxides (NO_x),
  - carbon monoxide (CO), and
  - particulate matter (PM), notably $PM_{2.5}$ and PM_{10}
  - ammonium ($NH_4^+ + OH^-$),



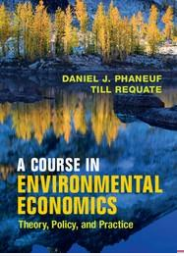
2.2 Air Pollution

- Sulfur dioxide emissions are the primary cause of acid rain.
- Acid rain is also responsible for the *Waldsterben* phenomenon.
- Climate changes include higher temperatures, more frequent extreme weather events, changing precipitation patterns, and rising sea levels.



2.2 Air Pollution

- Greenhouse gasses are natural components of the earth´s atmosphere whose presence at appropriate concentrations is necessary for life on the planet.
- Major GHGs: CO_2, CH_4 (methane), N_2O (laughing gas), CFCs
- Emissions from human activity increase their concentration in the atmosphere, thereby changing the planet´s heat absorption capacity and impacting the climate system.
- Reducing carbon emissions is a particularly difficult problem.
- Air pollutants affect human-well being through their impact on health, though there are also significant ecological impacts.



2.3 Land Pollution

- The concept of land pollution broadly includes:

a) Dumping of conventional, hazardous, and radioactive waste materials; and
b) The alteration of landscapes that reduces recreation or preservation services, damages biodiversity, and destroys carbon sinks.

- Prior to large-scale environmental regulations many industrial operations accumulated and stored hazardous waste on-site.

- The cleanup is a policy objective for environmental agencies based on the health and safety risks they might convey.

- Landscape alteration is usually not classified as pollution per se, but it can have prefunded effects on the environment.