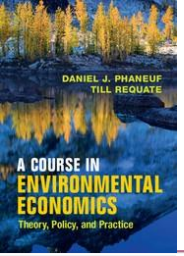


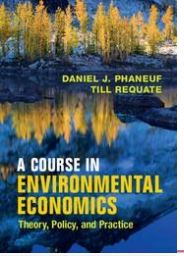
Environmental Economics

Lecture 2,
(Chapter 3 from textbook)

Introduction to the Theory of Environmental Policy

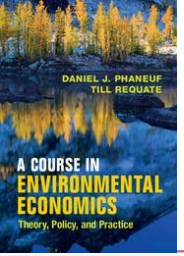


3.1 A Simple Model of Damages and Costs



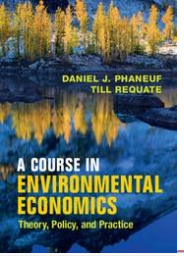
Major assumptions in this chapter

- Full information about preferences and technology.
- Fixed pollution technologies, separable from output technologies.
- Pollutants = flow pollutants.
- Markets fully competitive.
- No pre-existing, non-environmental distortions.
- No spatial, temporal or international dimensions.



Preview of main insights

- For optimal environmental policy, the marginal cost of abatement should be equal to the marginal damage of pollution.
- If pollutants are homogeneous, the cost of removing the last pollution unit should be equal across the different pollution sources.
- Market-based instruments that provide incentives through prices are the most efficient instruments.



3.1.1 Damage Function

- An individual's utility function is quasi-linear:

$$U_i(y_i, E) = y_i - D_i(E) \tag{3.1}$$

- Assume, households' individual damage functions are known.

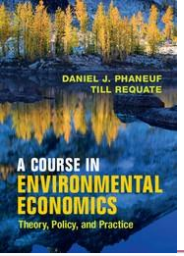
- The *aggregate damage function* is found by summing over the individual disutility functions

$$D(E) = \sum_{i=1}^{I} D_i(E) \tag{3.2}$$

where *I* denotes the number of households.

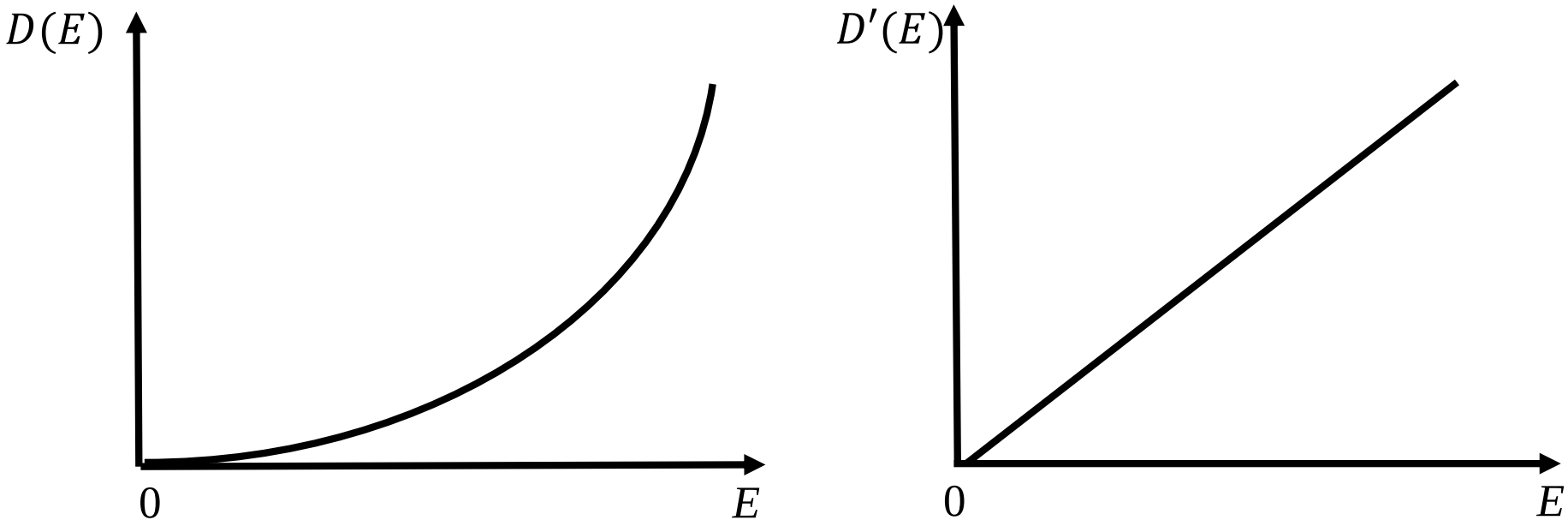
- Assume: $D'(E) > 0, \quad D''(E) \geq 0$

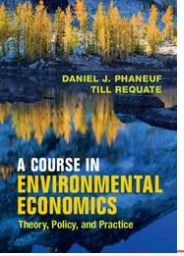
i.e. *marginal damage* is positive and either constant or increasing.



3.1.1 Damage Function

Figure 3.1: Damage and marginal damage for D“(E) >0





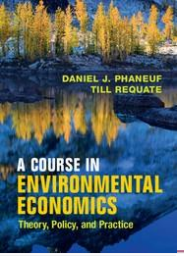
3.1.2 Abatement Costs

- Assume operating and pollution reduction costs are separable.
- We define the cost of pollution reduction, or the abatement cost function for firm *j*, by $C(e_j)$.
- Assume $\hat{e}_j$ is firm *j*'s maximal emission level such that:

$$C_j(e_j) = 0, \quad \text{for} \quad e_j \geq \hat{e}_j$$

- A marginal reduction in emissions marginally increases costs. We therefore define *marginal abatement costs* as

$$MAC_j(e_j) = -C'_j(e_j) > 0, \quad e_j < \hat{e}_j \qquad (3.3)$$



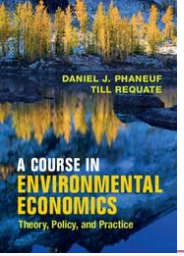
3.1.2 Abatement Costs

- We assume that the marginal abatement cost increases when emissions are reduced.
- Therefore the abatement cost function is weakly convex

$$MAC'_j = -C''_j\left(e_j\right) \leq 0, \quad \text{for} \quad e_j < \hat{e}_j \tag{3.4}$$

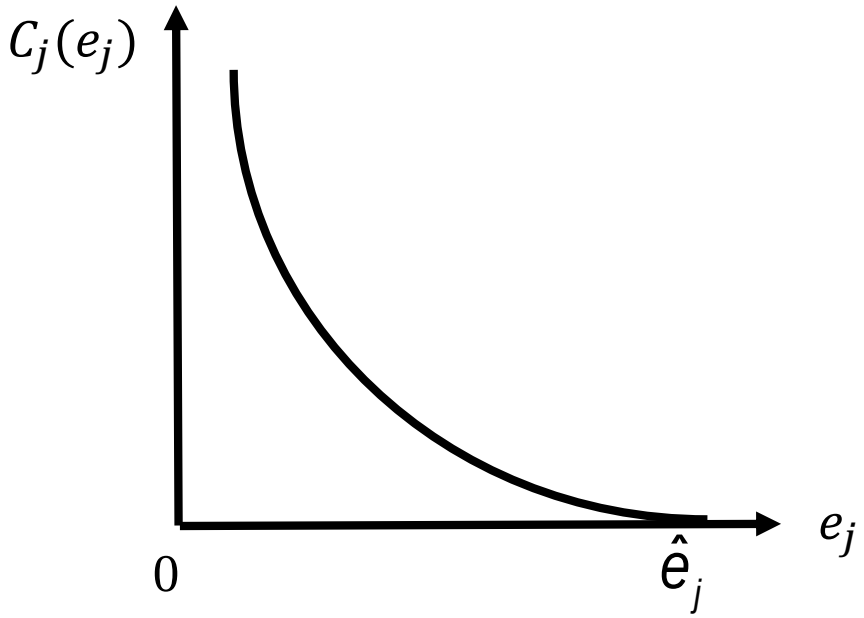
or:

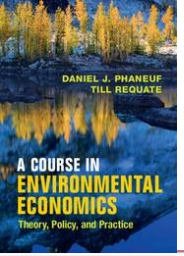
$$C''_j\left(e_j\right) \geq 0, \quad \text{for} \quad e_j < \hat{e}_j$$



3.1.2 Abatement Costs

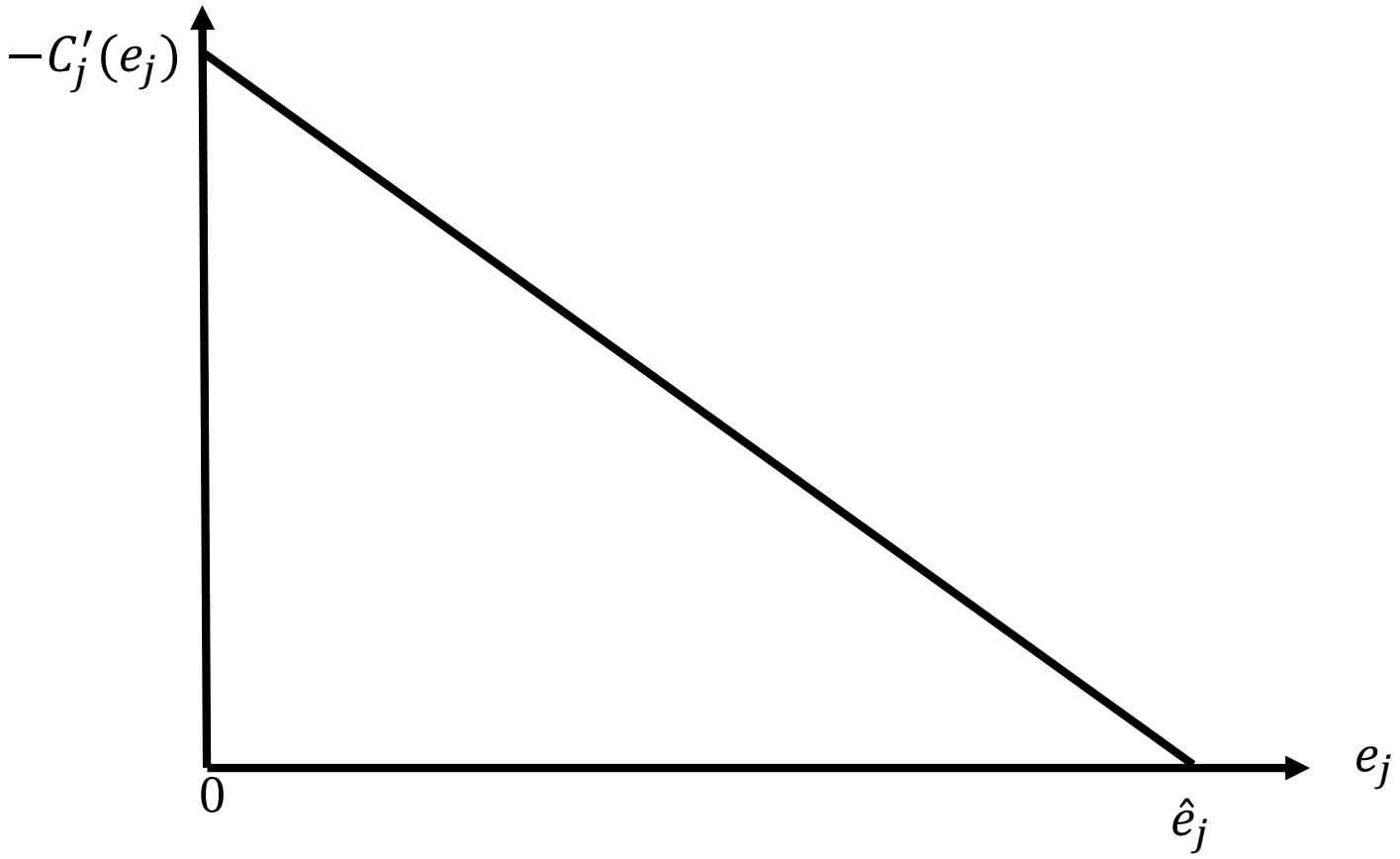
Figure 3.1 Abatement cost function

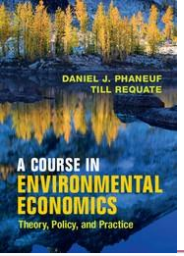




3.1.2 Abatement Costs

Figure 3.3: Marginal abatement cost function



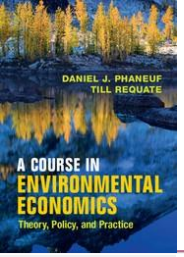


3.1.3 Efficient Allocation

- Emissions from firms negatively impact consumers or other firms.
- Emission control has an opportunity cost for firms.
- *SC* denotes the *total social cost*

$$SC(e_1,...,e_j) = \sum_{j=1}^{J} C_j(e_j) + D(E) \qquad (3.5)$$

- where $E = \sum_{j=1}^{J} e_j$ are aggregate (or total) emissions
- *SC* is to be minimized by choosing each firm's emission level.



3.1.3 Efficient Allocation

$$SC(e_1,...,e_j) = \sum_{j=1}^{J} C_j(e_j) + D(E) \qquad (3.5)$$

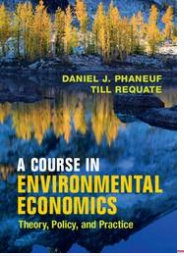
- Differentiating SC with respect to e_j we obtain:

$$C'_j(e_j) + D'(E) = 0 \qquad (3.6)$$

- or:

$$-C'_j(e_j) = D'(E), \quad \forall j = 1,...,J \qquad (3.7)$$

- i.e., each polluter's *marginal abatement costs equals marginal damage*.



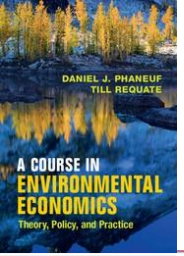
3.1.3 Efficient Allocation

$$-C'_j(e_j) = D'(E), \quad \forall j = 1,...,J \qquad (3.7)$$

- (3.7) can be used to further show that:

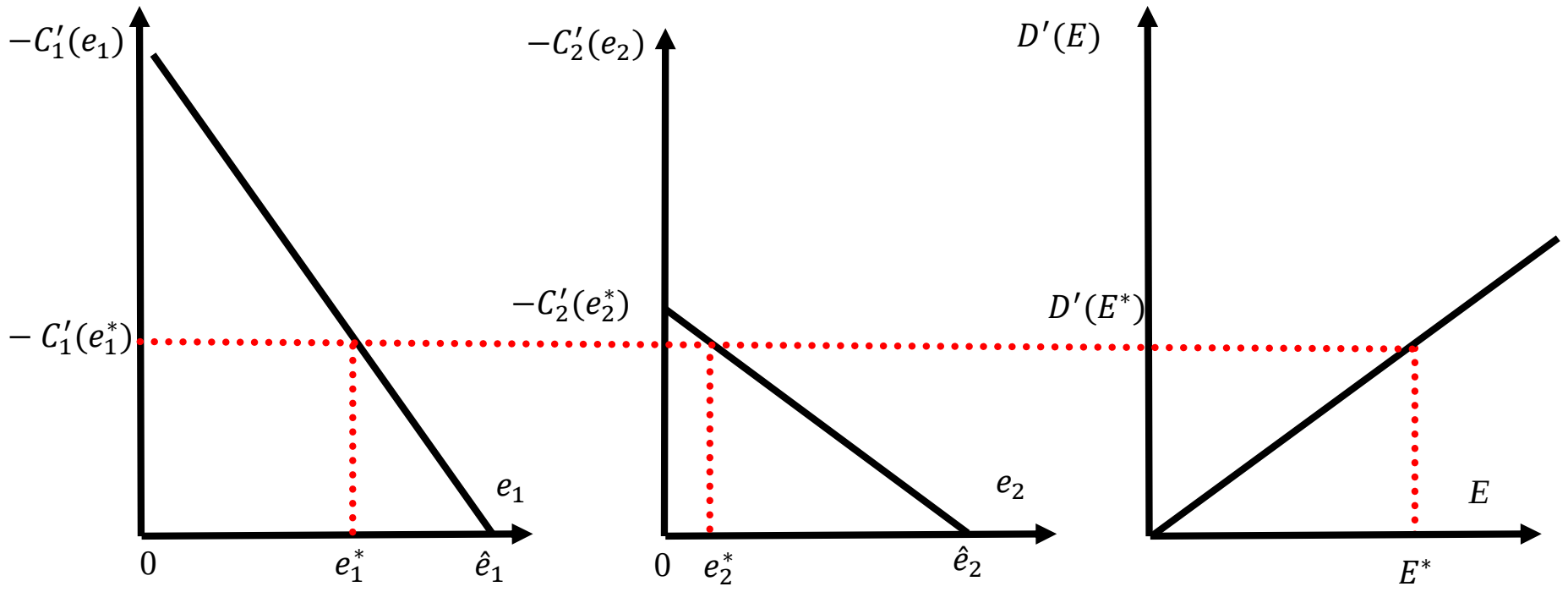
$$-C'_j(e_j) = -C'_k(e_k), \quad \forall j,k = 1,...,J \qquad (3.8)$$

- i.e. *marginal abatement costs are equal across all polluters.*

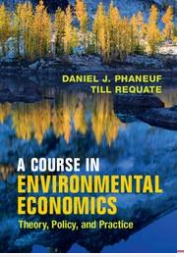


3.1.3 Efficient Allocation

Figure 3.1 Pollution damages, costs, and efficient emission level

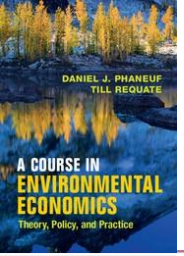


Panel A **Panel B** **Panel C**

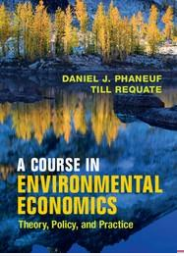


3.2 Property Rights and Coase Theorem

See later (optional)



3.3 Environmental Policy Instruments



3.3 Environmental Policy Instruments

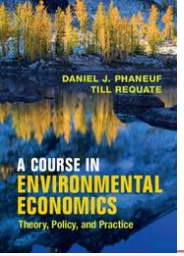
I. Command and Control

II. Emission Tax

III. Auctioned Pollution Permits

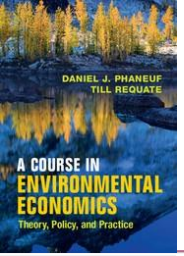
IV. Freely Distributed Transferable Permits

V. Subsidies



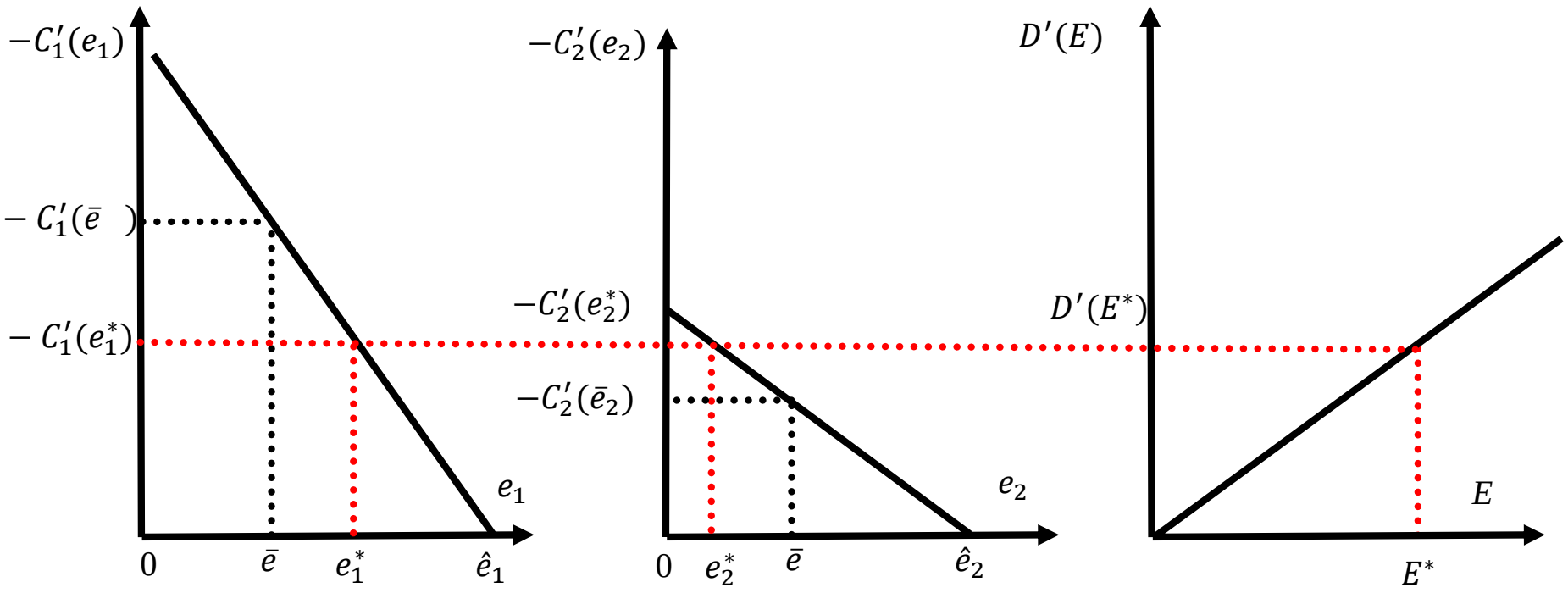
3.3.1 Command and Control

- Polluters are required to carry out a prescribed pollution-reducing action.
- Most common policy is an emission limit.
- Regulator sets emission standard: $e_j \leq \bar{e}$
- One option would be: $\bar{e} = E^*/J$
- where E^* is socially optimal level of aggregate emissions.
- Obviously, a **uniform emission limit** is not optimal if abatement costs among polluters are asymmetric, as marginal abatement costs are typically not equalized.

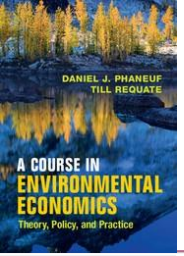


3.1.3 Efficient Allocation

Figure Emission standads

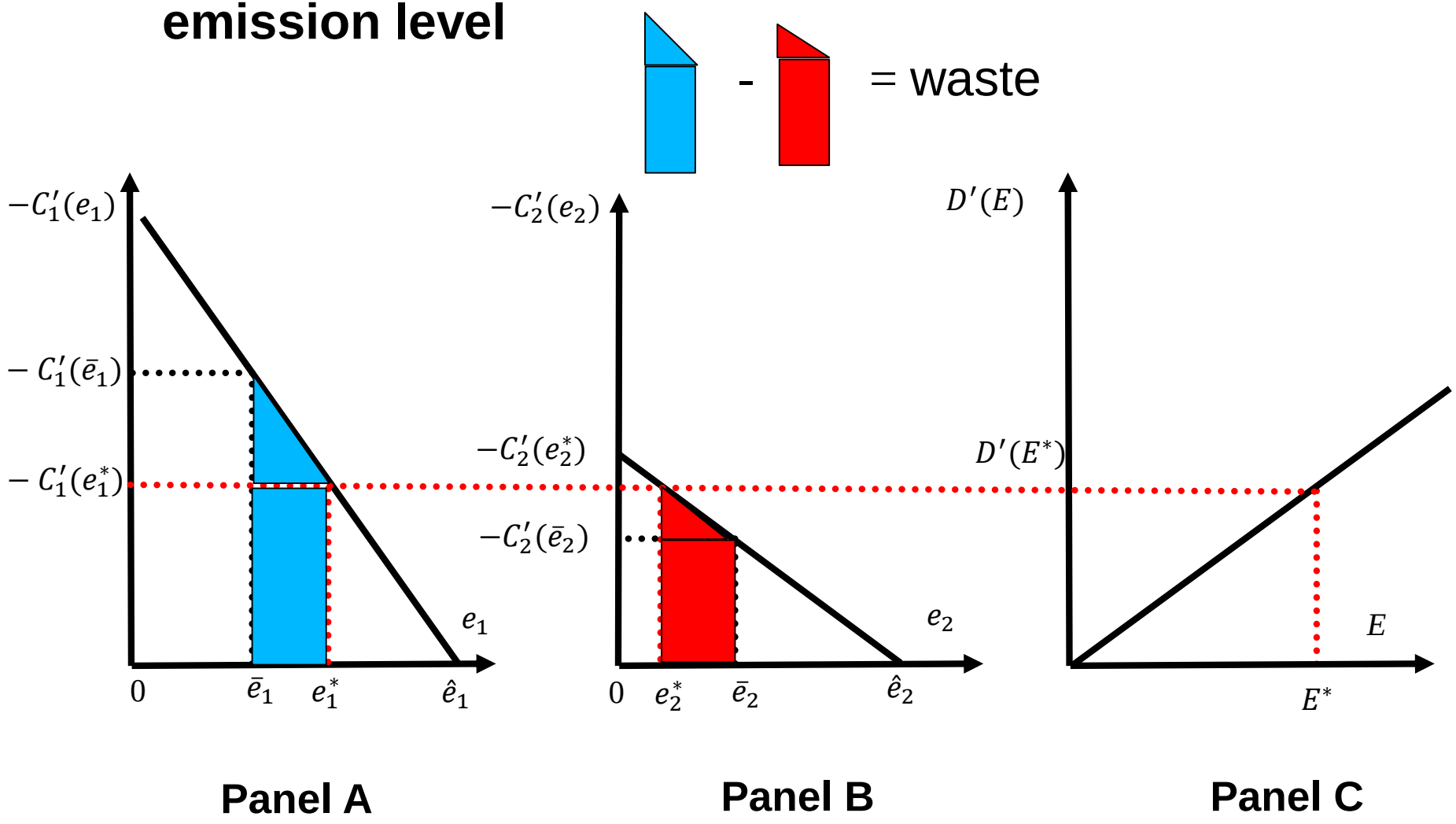


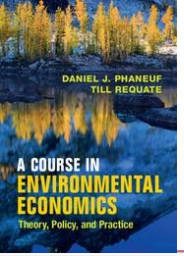
Panel A **Panel B** **Panel C**



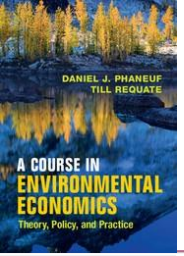
3.1.3 Efficient Allocation

Figure 3.1 Pollution damages, costs, and efficient emission level





3.3.2 Emission Taxes



3.3.2 Emission Taxes

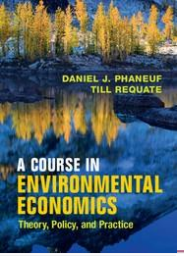
- Polluters pay a price (a tax) of a size τ per unit of pollution.
- Polluting firms' total pollution-related cost under taxation:

$$TC_j\left(e_j\right) = C_j\left(e_j\right) + \tau e_j \qquad (3.19)$$

$$\text{FOC}: \quad C_j'\left(e_j\right) + \tau = 0$$

$$or: \quad -C_j'\left(e_j\right) = \tau \qquad (3.20)$$

- The firms' optimal response is to reduce emissions until the marginal abatement rate is equal to the tax rate.



3.3.2 Emission Taxes

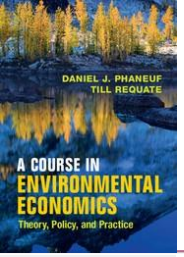
- If all firms face the same marginal tax rate, then all firms will have equal marginal abatement costs at their chosen emission levels.

$$MAC_j\left(e_j\right) \equiv -C_j'\left(e_j\right) = \tau = -C_j'\left(e_j\right) \equiv MAC_k\left(e_k\right) \quad \forall \quad j \neq k \tag{3.21}$$

- This induces individual emissions $e_j\left(\tau\right)$.

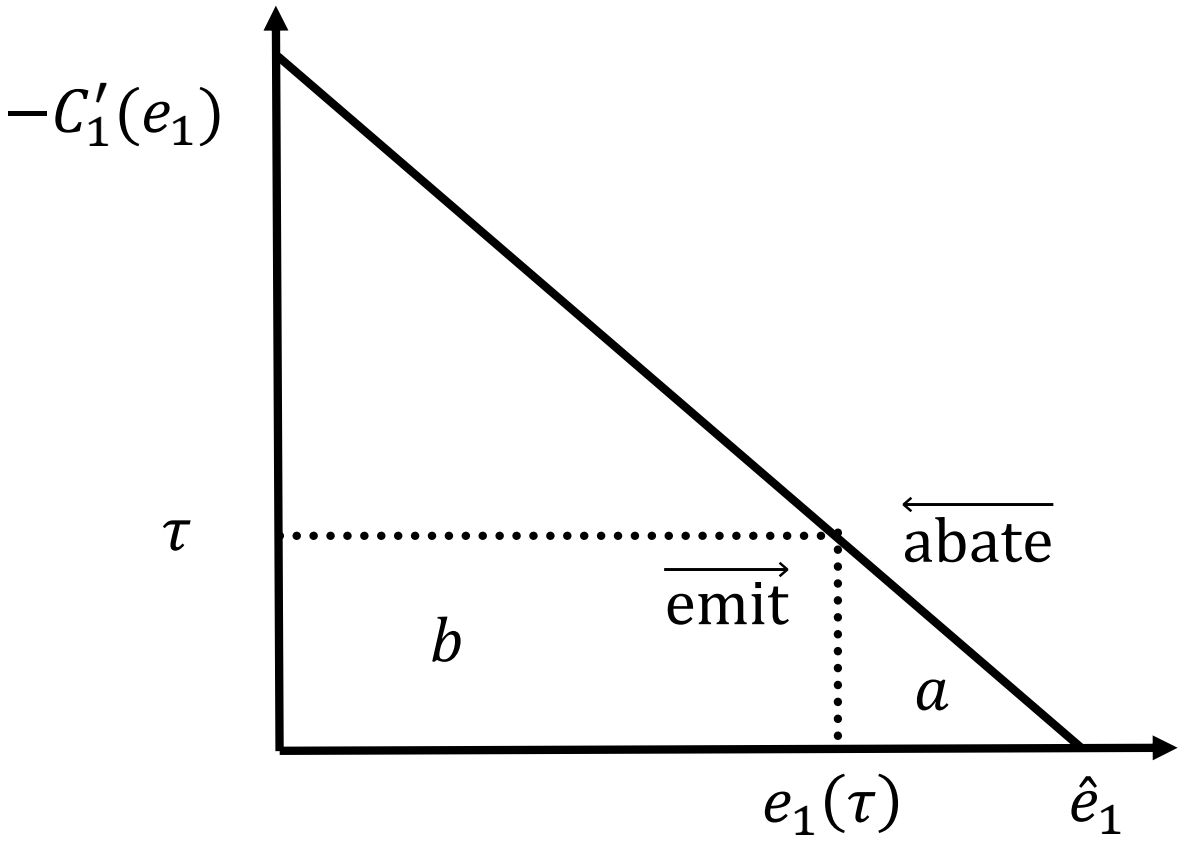
- And the aggregate emission level results in:

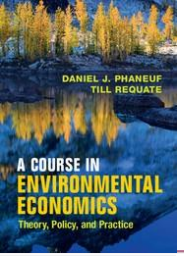
$$E\left(\tau\right) = \sum_{j=1}^{J} e_j\left(\tau\right) \tag{3.22}$$



3.3.2 Emission Taxes

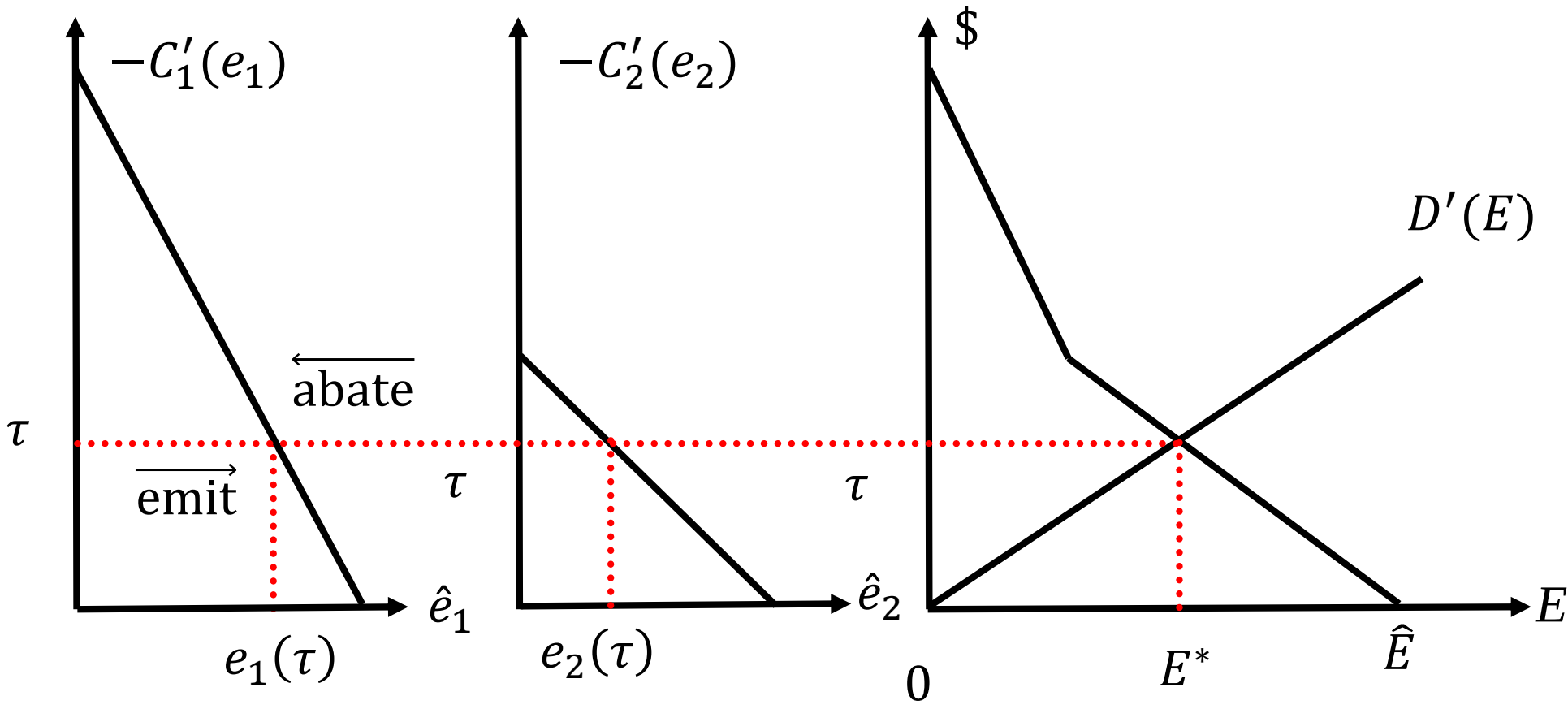
Figure 3.2 Emission taxes

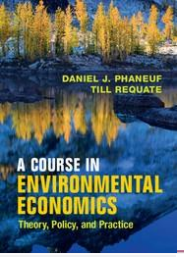




3.3.2 Emission Taxes

Figure 3.2 Emission taxes





3.3.2 Emission Taxes

Comparative Statics (how does the firm respond to changes in the tax rate)?

- Given the tax rate τ, firm chooses

$$-C_j'\left(e_j\right)=\tau \quad \Rightarrow \quad e_j=e_j(\tau) \tag{3.20}$$

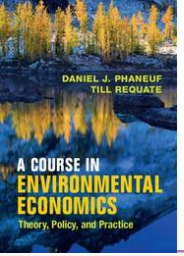
- Differentiating with respect to τ yields:

$$-C''_j\left(e_j(\tau)\right)\frac{de_j(\tau)}{d\tau}=1 \tag{3.23}$$

- or:

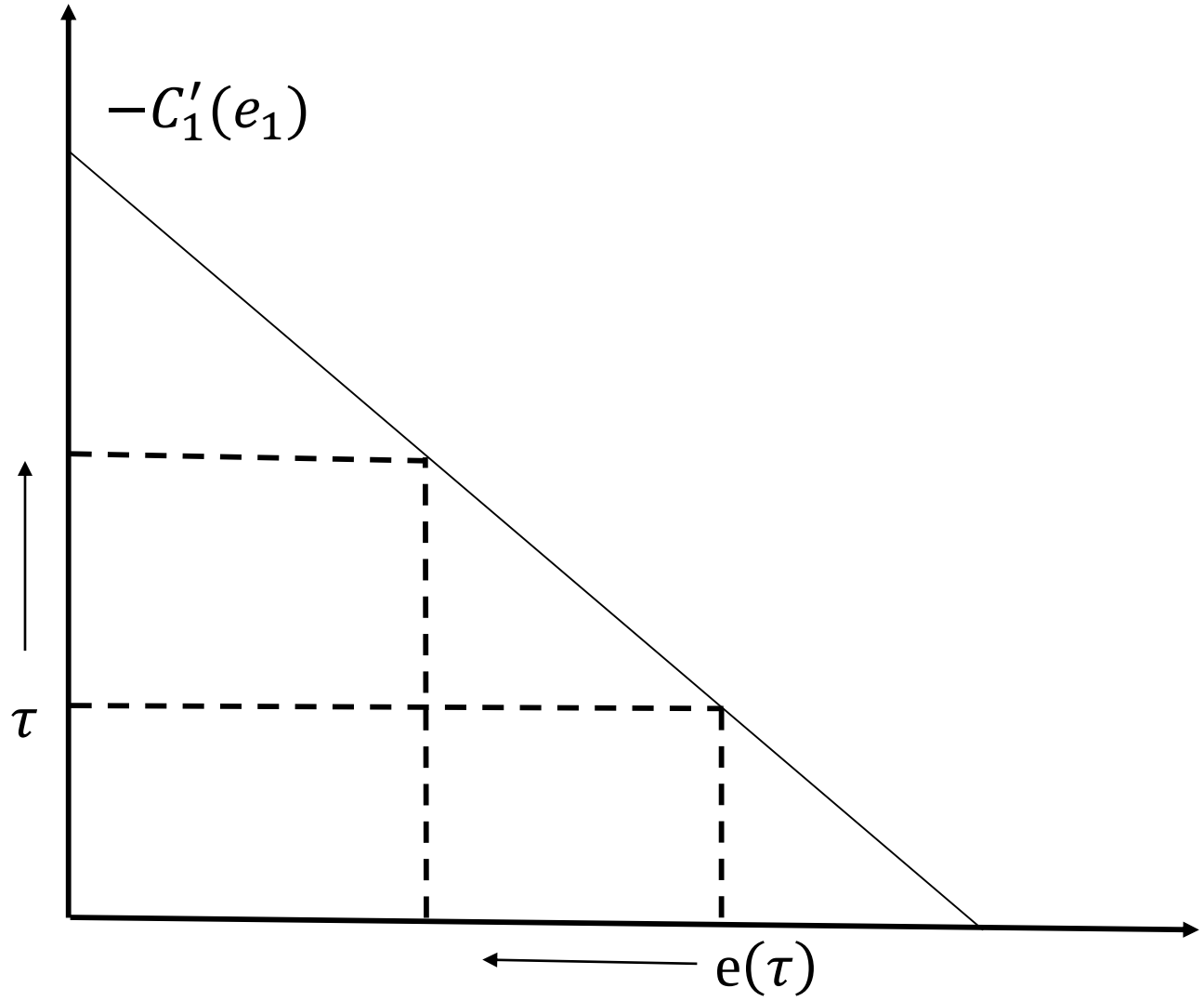
$$\frac{de_j(\tau)}{d\tau}=\frac{1}{-C''_j}<0 \tag{3.24}$$

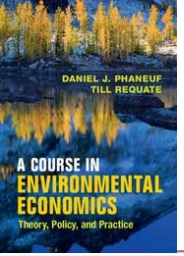
- i.e., higher taxes lead to lower emissions.



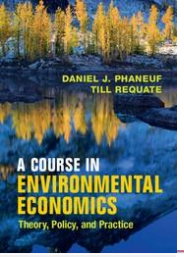
3.3.2 Emission Taxes

Figure 3.2 Emission taxes





3.3.3 Auctioned Pollution Permits



3.3.3 Auctioned Pollution Permits

- For a given time period government auctions off a fixed number of pollution rights (or allowances, permits).

- Firm‘s cost:

$$TC_j\left(e_j\right) = C_j\left(e_j\right) + \sigma e_j \qquad (3.25)$$

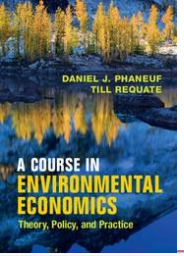
where σ = auction price for an emission right.

- Firm‘s f.o.c. for cost minimization: $-C_j'\left(e_j\right) = \sigma \quad \Rightarrow \quad e_j(\sigma)$

- Permit market equilibrium

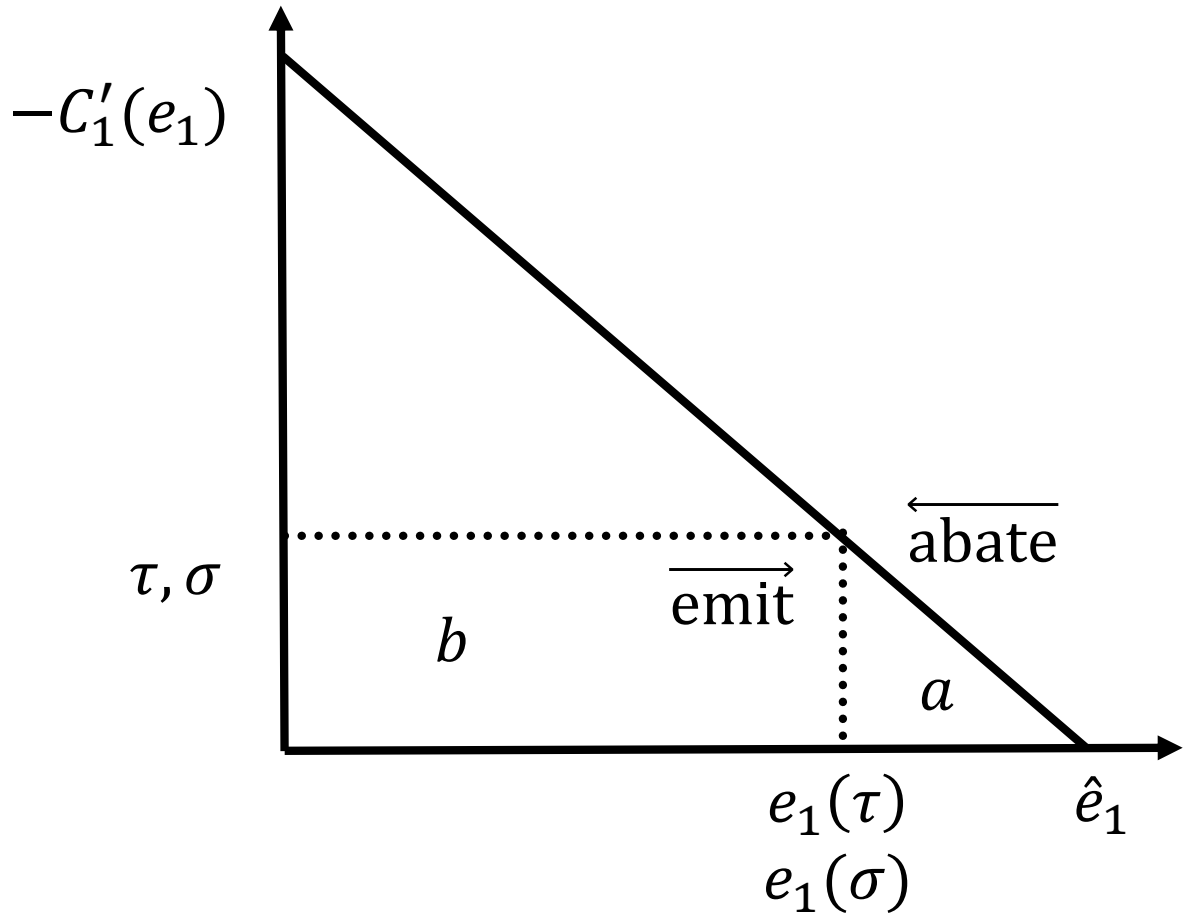
$$L = \sum_{j=1}^{J} e_j\left(\sigma\right) \qquad (3.26)$$

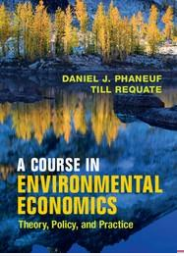
where L is the total supply of permits issued by the government.



Emission Taxes and Auctioned Permits

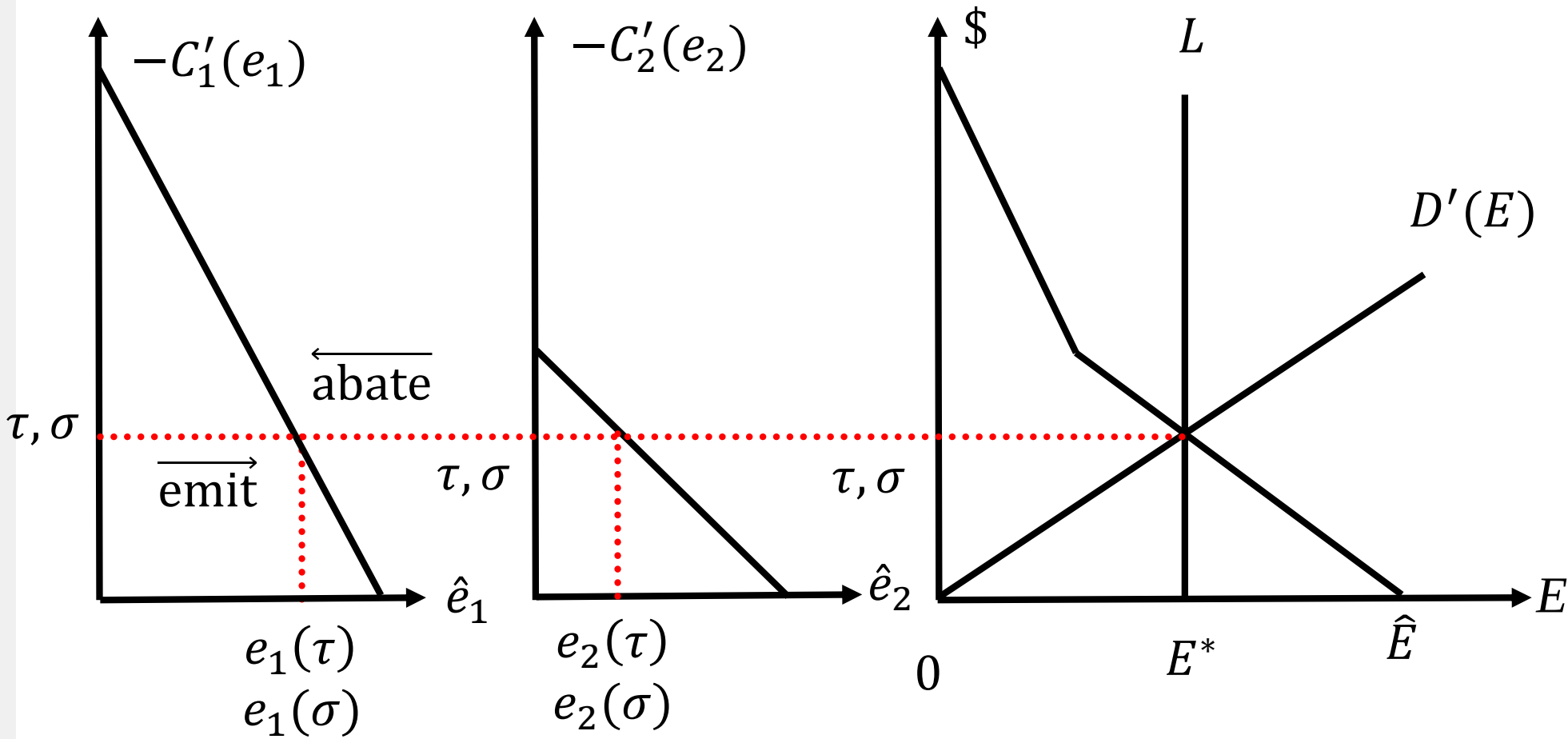
Figure 3.2 Emission taxes and auctioned permits

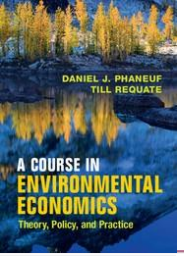




Emission Taxes and Auctioned Permits

Figure 3.2 Emission taxes and auctioned permits





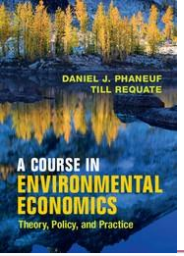
3.3.3 Auctioned Pollution Permits Proposition 3.2

Proposition:

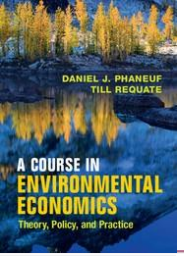
If the regulator knows the polluting industry ´s aggregate demand curve for emissions, or equivalently the aggregate marginal abatement cost curve, and if the firms behave as price takers on the permit market, the regulator can achieve an aggregate emission target $\bar{E}$ by:

a) Issuing a total amount of permits for auction $L = \bar{E}$; or
b) Charging an emission tax τ which leads to $\bar{E}$.
In this case $\tau(\bar{E}) = \sigma(L)$, where $\sigma(L)$ is the market clearing price in the auction.

Furthermore, with knowledge of the damage function $D(E)$ the regulator can implement the socially optimal emission level E^* using either instrument.



3.3.4 Freely Distributed Transferable Permits



3.3.4 Freely Distributed Transferable Permits

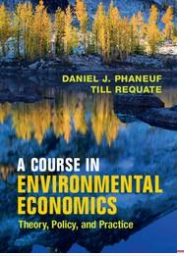
- Firms receive initial endowments of permits $\bar{e}_j$.
- Firm‘s cost function:

$$TC_j\left(e_j\right) = C_j\left(e_j\right) + \sigma\left(e_j - \bar{e}_j\right) \qquad (3.28)$$

FOC: $-C'_j\left(e_j\right) = \sigma$

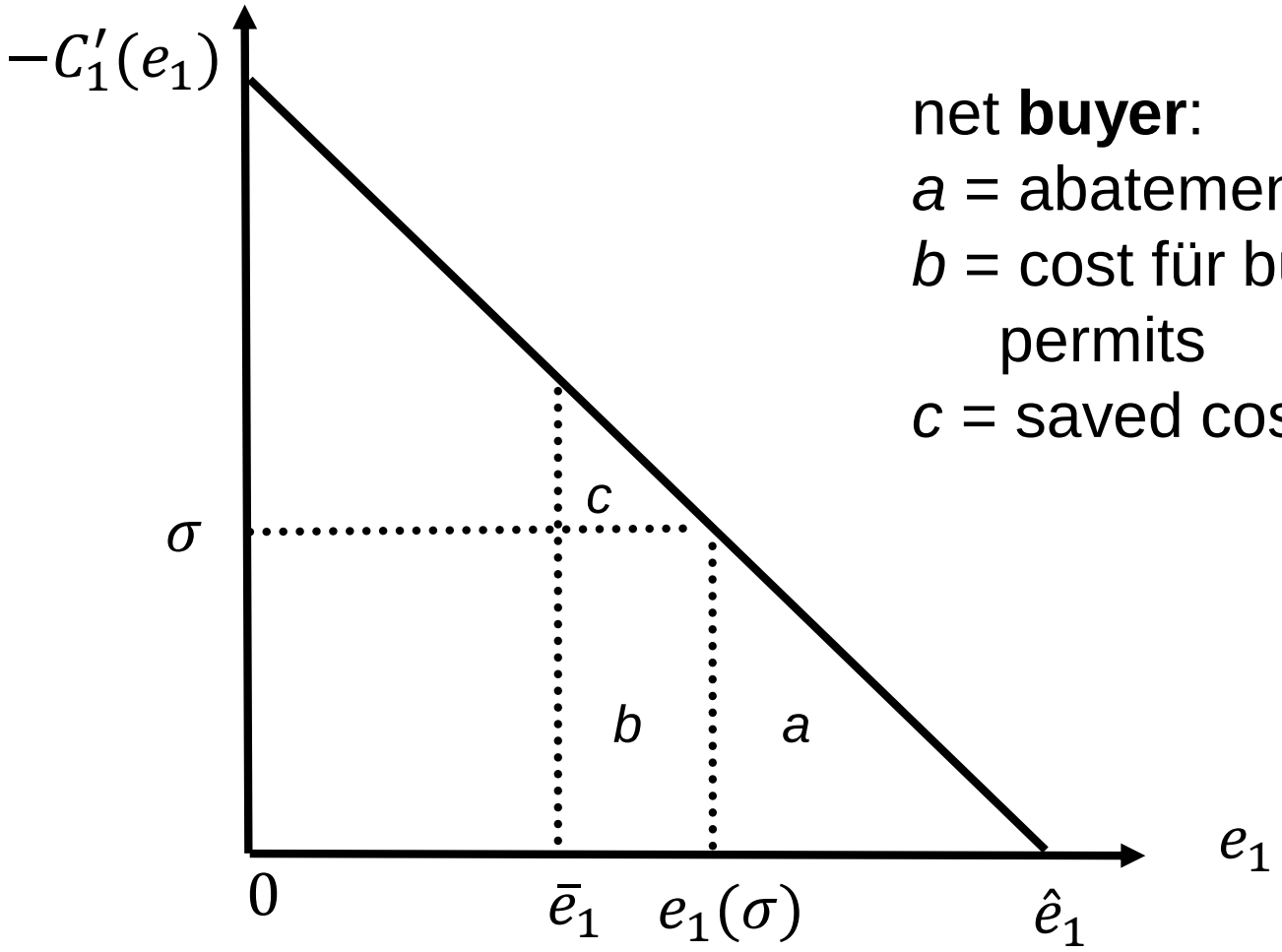
- Permit market equilibrium:

$$\sum_{j=1}^{J} e_j\left(\sigma\right) = \sum_{j=1}^{J} \bar{e}_j = L \qquad (3.29)$$

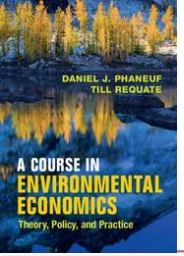


3.3.4 Freely Distributed Transferable Permits

Figure 3.3 Panel A: Freely distributed transferable permits

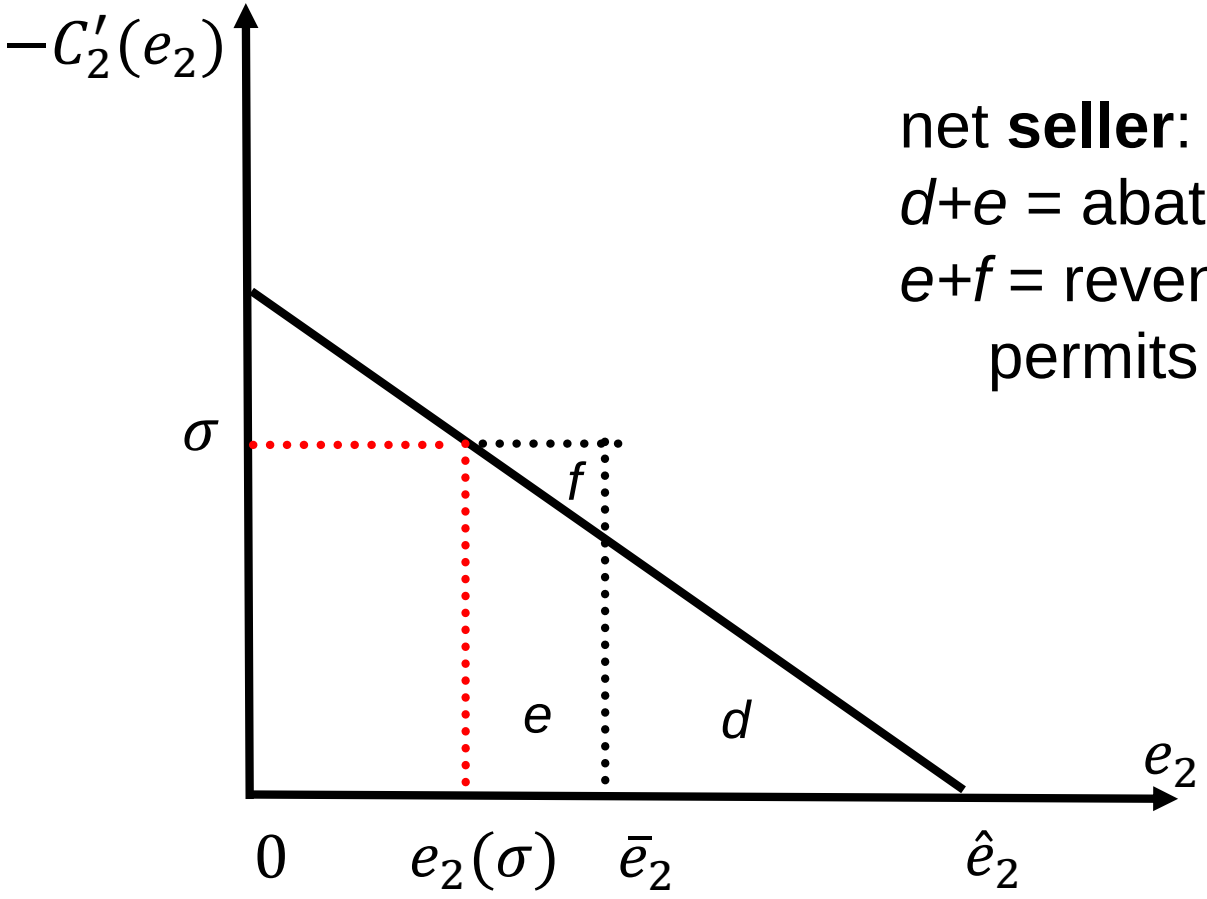


net **buyer**:
a = abatement cost
b = cost für buying permits
permits
c = saved costs thru trading

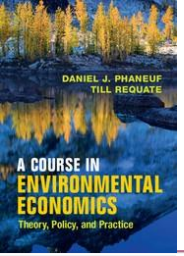


3.3.4 Freely Distributed Transferable Permits

Figure 3.3 Panel B: Freely distributed transferable permits

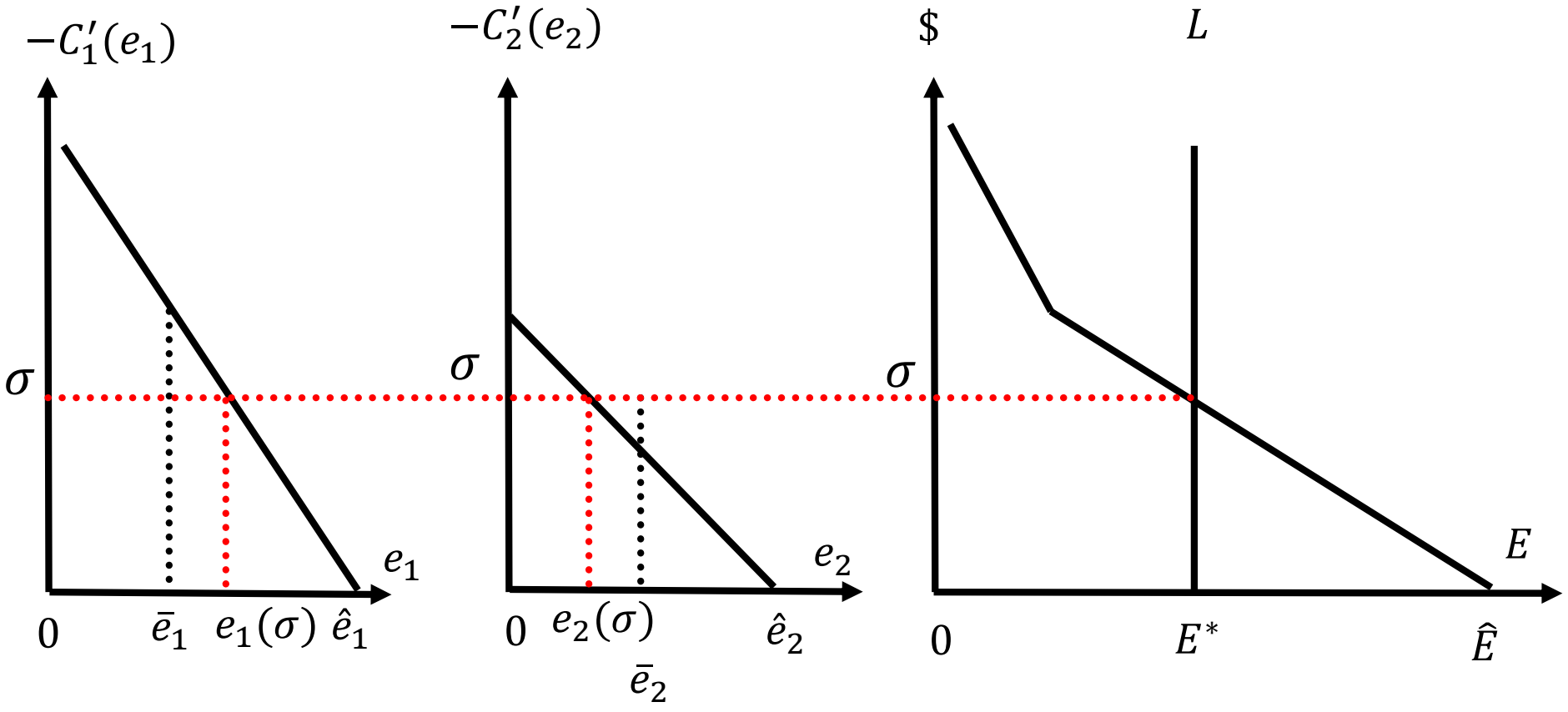


net **seller**:
d+*e* = abatement cost
e+*f* = revenues from selling permits

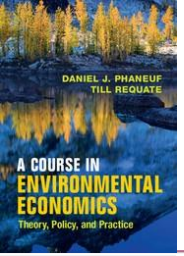


3.3.4 Freely Distributed Transferable Permits

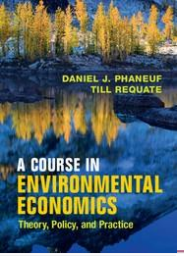
Figure 3.3: Freely distributed transferable permits



Panel A **Panel B** **Panel C**



3.3.5 Subsidies



3.3.5 Subsidies

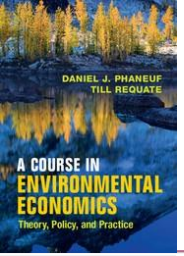
- Firm receives a payment ζ for each unit of pollution abated below some reference level.

$$TC_j\left(e_j\right) = C_j\left(e_j\right) + \zeta\left(e_j - \hat{e}_j\right) \qquad (3.30)$$

$$\text{FOC}: -C_j'\left(e_j\right) = \zeta$$

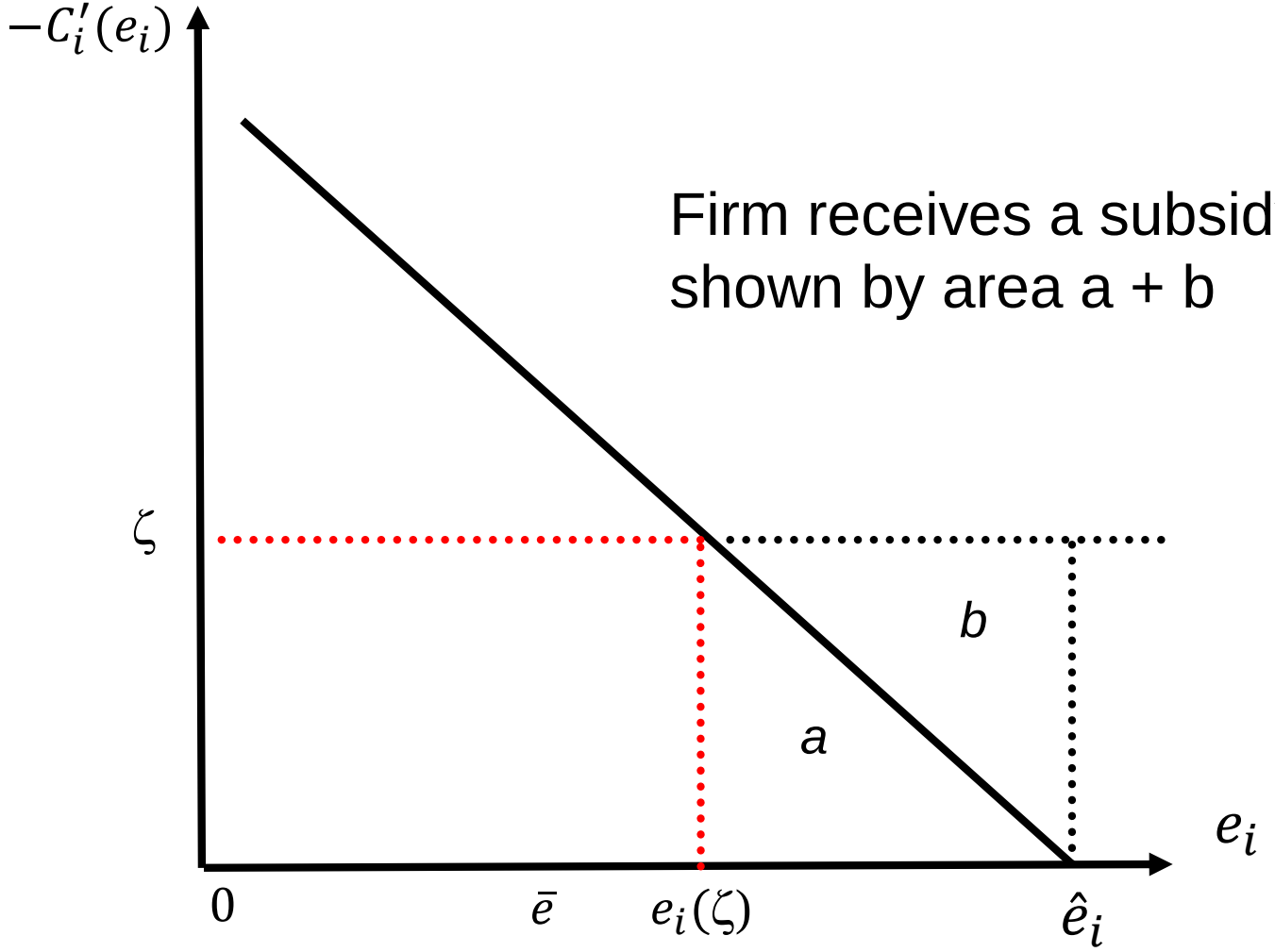
- Per unit subsidy has the same effect as an emission tax.

- Firms choose the emission level that equates marginal abatement cost to the per unit subsidy.

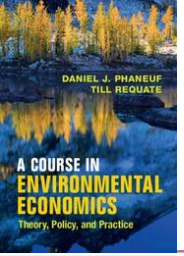


3.3.5 Subsidies

Figure 3.4: Subsidized abatement



Panel A



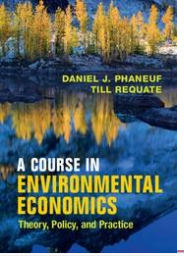
3.3.5 Subsidies

- The amount $\zeta \hat{e}_j$ is in effect a lump sum transfer to the firm that has no impact on marginal decisions.

- Total payments to polluting firms:

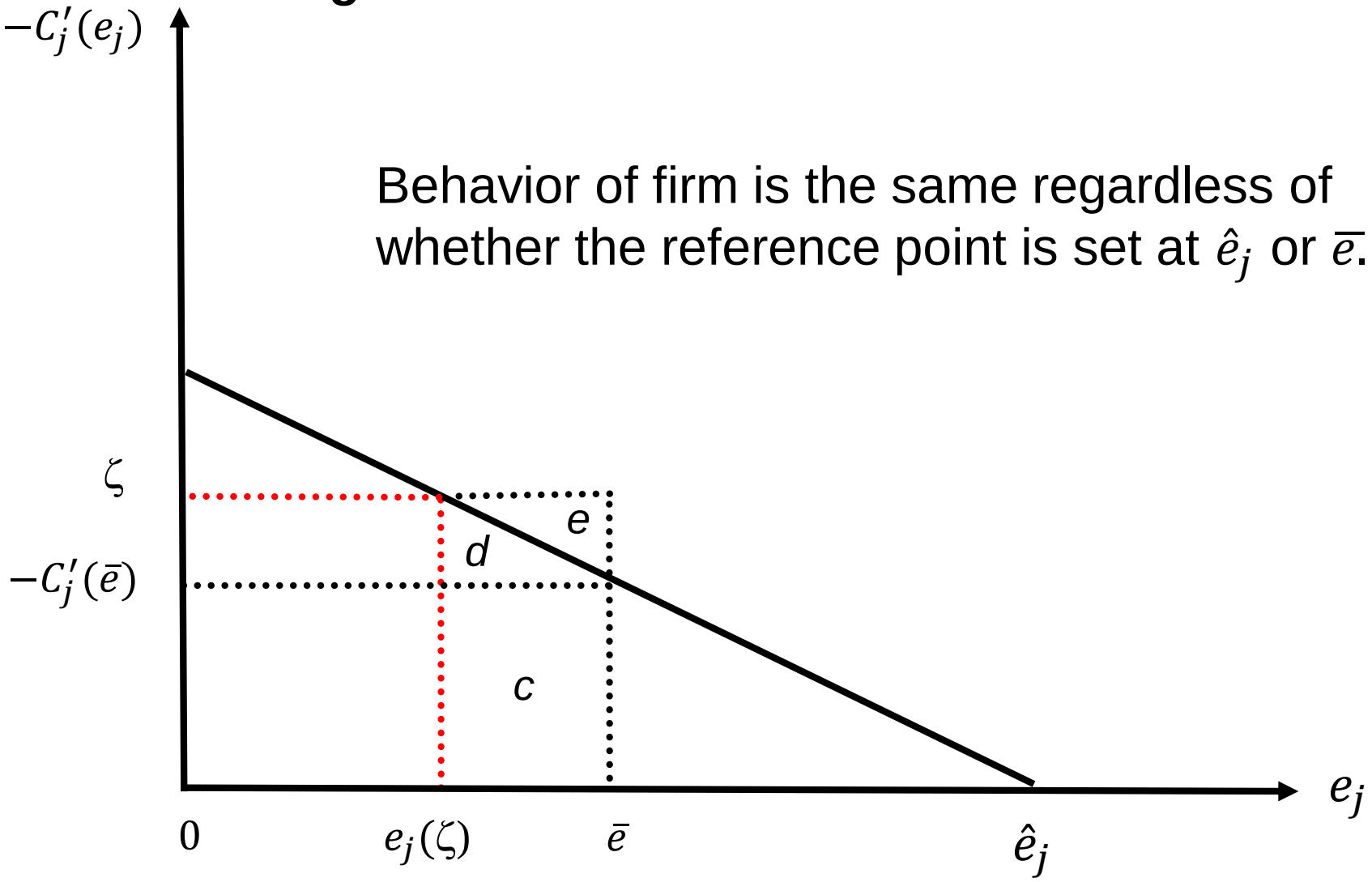
$$\zeta \sum_{j=1}^{J} \left(\hat{e}_j - e_j \right)$$

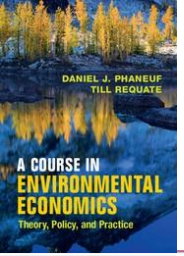
- Government can reduce transfers to the industry by reducing the reference emission point below which the firms begins to receive the subsidy.



3.3.5 Subsidies

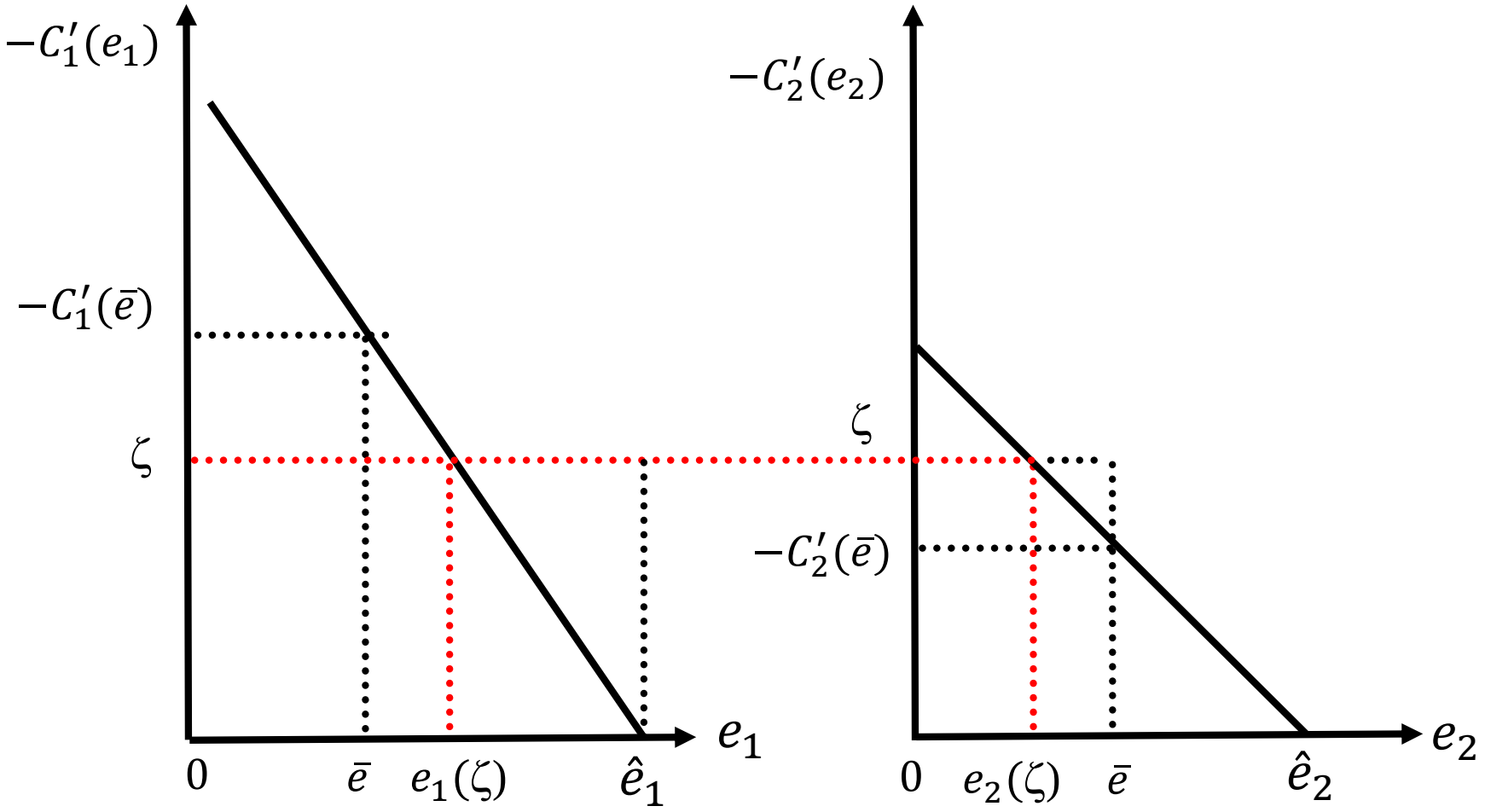
Figure 3.4 Subsidized abatement

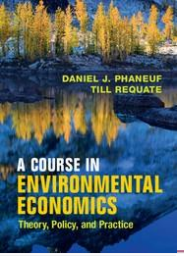




3.3.5 Subsidies

Figure 3.4: Subsidized abatement





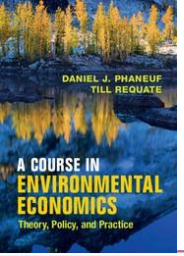
3.3.5 Subsidies

- Mixed tax/subsidy scheme.
- The polluting firm receives a subsidy for each united abated below some standards and pays for all units emitted above the standard.

$$TC_j\left(e_j\right) = C_j\left(e_j\right) + \zeta\left(e_j - \hat{e}_j\right) \qquad (3.31)$$

$\left(e_j - \hat{e}_j\right) > 0$: firm is paying a tax bill

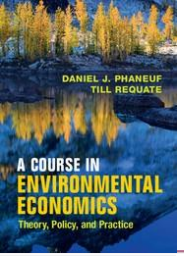
$\left(e_j - \hat{e}_j\right) < 0$: firm is receiving a subsidy payment



3.4 Aggregate Marginal Abatement Cost Curve

- The aggregate marginal abatement cost curve is the horizontal summation of the individual firms‘ marginal abatement costs.

- The aggregate marginal abatement cost curve tells us the efficient marginal abatement cost level for each firm for any aggregate emission target E.



3.4 Aggregate Marginal Abatement Cost Curve

- Suppose firms pay a per unit of tax τ for each united emitted:

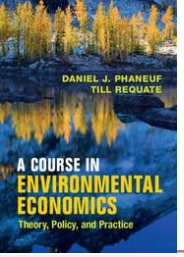
$$-C'_j\left(e_j\right)=\tau \tag{3.32}$$

- Aggregate for emissions:

$$E(\tau)=\sum_{i=1}^{N} e_j\left(\tau\right) \tag{3.33}$$

- Aggregate marginal abatement cost curve is derived by inverting:

$$AMAC=E^{-1}(\bullet) \tag{3.34}$$



3.4 Aggregate Marginal Abatement Cost Curve

- Example: Let:

$$C_j\left(e_j\right) = (a - b_j e_j)^2 / (2b_j) \qquad (E.1)$$

$$\Rightarrow \quad -C_j'\left(e_j\right) = a - b_j e_j \qquad (E.2)$$

- Let p be a price for emissions (a tax or a permit price)
- Then the demand for emissions is given by:

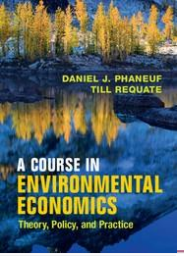
$$-C_j'\left(e_j\right) = a - b_j e_j = p \qquad (E.3)$$

$$\Rightarrow \quad e_j = \frac{a - p}{b_j}$$

- Now we sum up the demand over the firms:

$$E(p) = \sum_{i=1}^{J} e_j(p) = \sum_{i=1}^{J} \frac{a - p}{b_j} = \sum_{i=1}^{J} \frac{a}{b_j} - p\sum_{i=1}^{J} \frac{1}{b_j} = A - Bp \qquad (E.4)$$

where $A = \sum_{i=1}^{J} \frac{a}{b_j}, \quad B = \sum_{i=1}^{J} \frac{1}{b_j}$



3.4 Aggregate Marginal Abatement Cost Curve

- Now we invert $E(p)$ by solving

$$E = A - Bp \qquad (E.4)$$

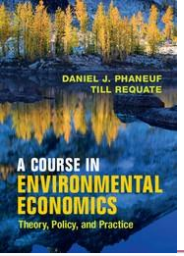
- for *p:*

$$p = (A - E)/B \qquad (E.5)$$

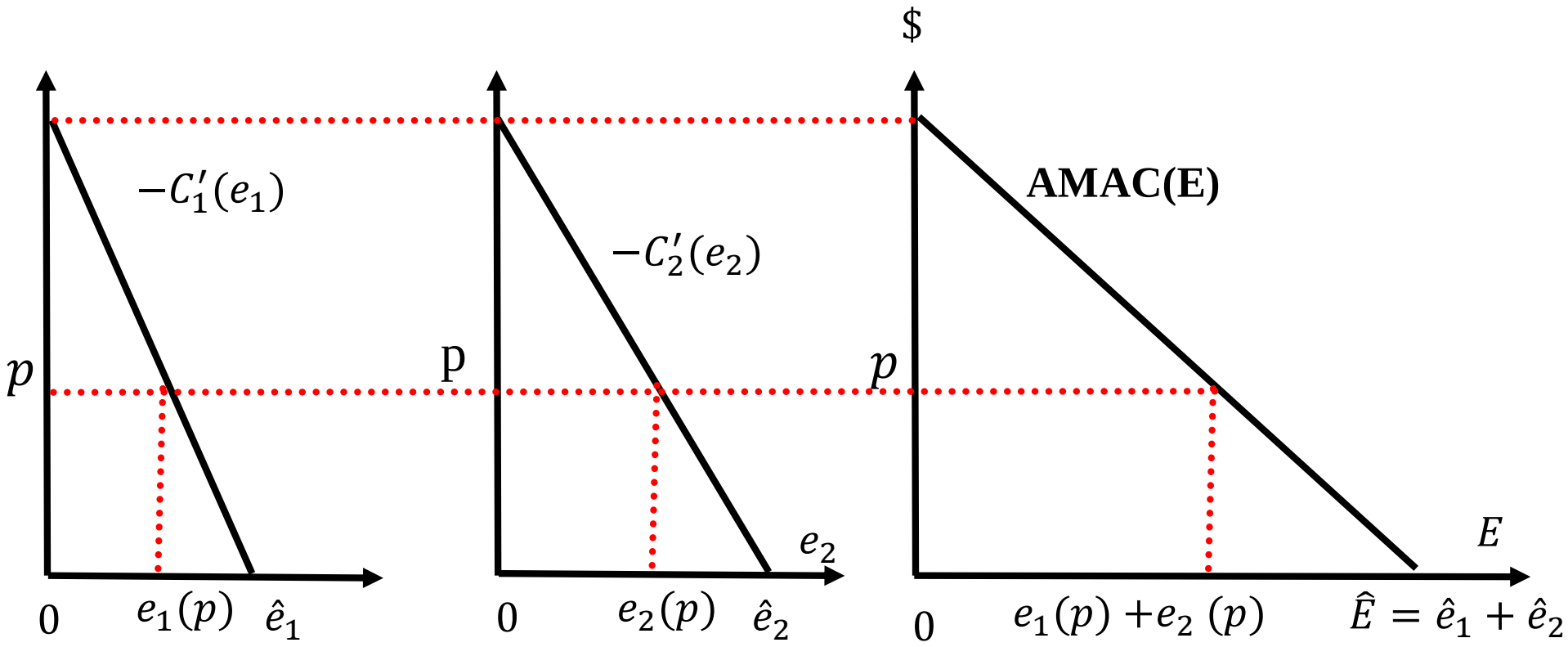
- But the right hand side is the aggregagte marginal abatement cost curve:

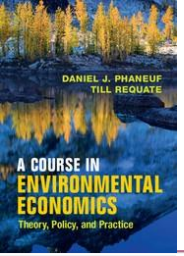
$$AMAC = E^{-1}(\bullet) = \frac{A - E}{B} \qquad (E.6)$$

- Note that for simplicity, we chose the same *a* for each firm.
- If the *a's* are different across firms, say a_i we would obtain a kinked aggregate marginal abatement cost curve.

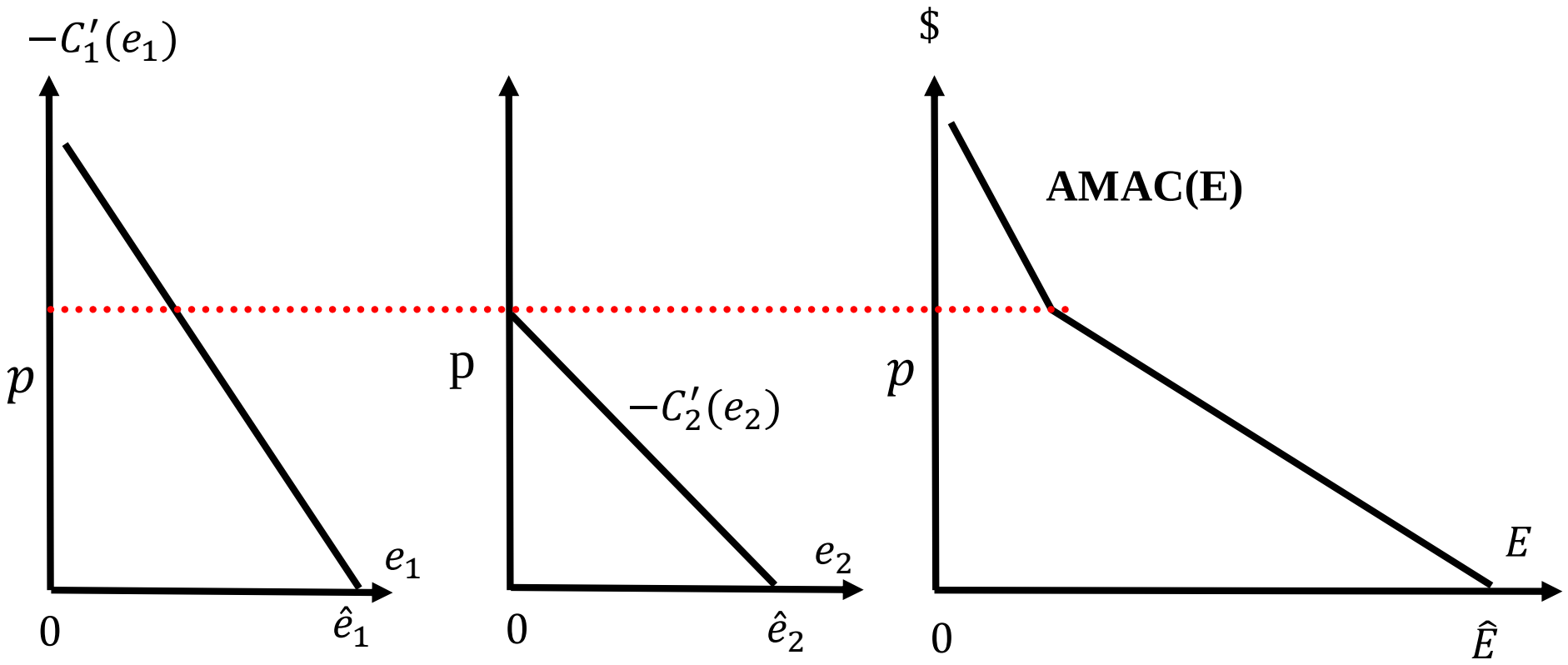


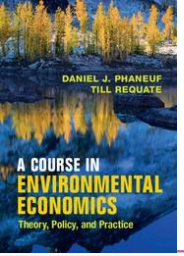
The AMAC: equal intercepts



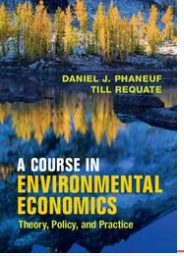


The AMAC: different intercepts





3.2 Property Rights and Coase Theorem

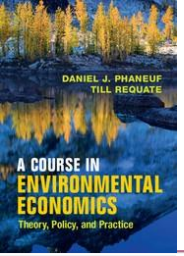


3.2 Property Rights and Coase Theorem

- Consider one firm (polluter) and just one affected household.
- A simple assignment of property rights for pollution to either the firm or the household and private negotiations between the parties may lead to the optimal level of pollution (Coase, 1960).

Case I: household owns the right of zero pollution.

- Firm can suggest a contract consisting of an emission level and a compensation for pollution: (E, θ).
- household can $\begin{cases} accept \\ refuse \end{cases}$ the contract
- Negotiating is costly, tr = transaction costs (incurred by firm).



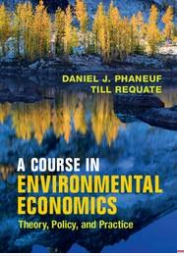
3.2.1 Household Ownership of Pollution Rights

- In order to make the household accept the contract, the firm needs to compensate the household for all damage, i.e. choose $\theta \geq D(E)$.
- If the firm has all the bargaining power, it will choose: $\theta = D(E)$
- Then the firm's total cost are given by:

$$TC(E) = C(E) + \theta + tr = C(E) + D(E) + tr \qquad (3.9)$$

And its choice of E results in the first order condition:

$$-C'(E) = D'(E) \qquad (3.10)$$

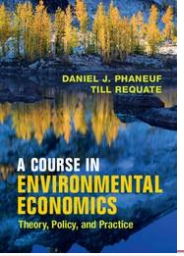


3.2.1 Household Ownership of Pollution Rights

- Transaction costs tr must not exceed the gains from negotiation for the efficient outcome

$$tr \leq C(0) - \left[C(E^*) + D(E^*)\right] \qquad (3.11)$$

i.e., the difference between the firm's costs at $E = 0$ and at the social cost in the optimum E^*.



3.2.2 Firm Ownerships of Pollution Rights

Case II: the firm owns the pollution rights:

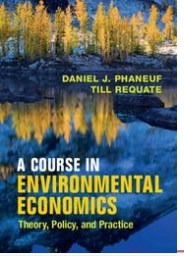
- The household first suggests a compensation contract (E, θ).
- Firm can $\begin{cases} accept \\ refuse \end{cases}$ the contract.
- Firm will accept if $\theta \geq C(E)$. For $\theta = C(E)$ the
- household's utility maximization problem is

$$\max_{E} \left\{ y - \left(D(E) + C(E) + tr \right) \right\} \qquad (3.12)$$

$$\Rightarrow \quad -C'(E) = D'(E) \qquad (3.13)$$

- Contract pays off if transaction costs do not exceed the potential gains from negotiations: (where $E =$ unregulated emissions)

$$tr \leq D(E) - \left[D(E^*) + C(E^*) \right] \qquad (3.14)$$



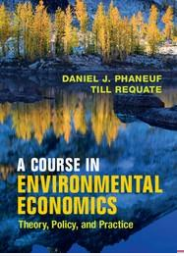
Proposition 3.1: Coase Theorem

Suppose party A imposes an externality on party B. Provided transaction costs are sufficiently small, irrespective of the initial allocation of property rights: Then

(a) there exists an efficient contract describing a socially optimal level of pollution E^* and a transfer payment θ from one party to the other which makes both parties at least as well off as without the contract.

(b) the efficient contract can be interpreted as the outcome of a sub-game perfect equilibrium of a sequential game, where the non-property right owner suggests a contract to the property right owner who either accepts or rejects the contract.

The Coase Theorem suggests that with an externality problem the parties have an incentive to solve the problem in a decentralized way be negotiating and contract.



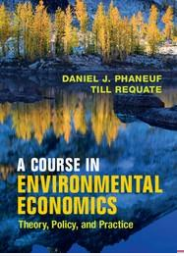
Proposition 3.1: Coase Theorem

Drawbacks:

The Coase Theorem is unlikely to work if there a many victims.

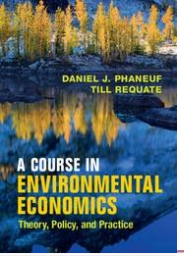
Transaction costs may be too high for any single victim.

The state needs to take the role to represent the victims and implement some regulation.



3.2.4 Polluter Pays Principle

- The **Polluter-Pays-Principle** (PPP) requires that the polluter always pays all the damage.
- In the Coase-Theorem above, this corresponds to the case where the household has a right for a clean environment.
- The PPP works fine of the victim can nothing do about the pollution.
- But is it efficient, if the victim has access to some defense measures?



3.2.4 Polluter Pays Principle

Extended model:

- Damage function $D(E, x)$,

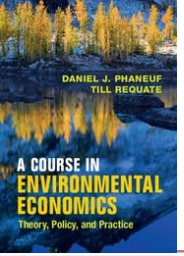
  where x is a private market good that mitigates the damage to the consumer.

  We can think about a household engaging in **defense measures** by buying some stuff x.

- Assumption: $D_x < 0$

  $D_{Ex} < 0$

implying that an increase in x causes both total und marginal damages to be reduced.



3.2.4 Polluter Pays Principle

- Household's problem:

$$\max_{x}\left\{y-\left[D(E,x)+px\right]\right\} \qquad (3.15)$$

where p is the market price of x
$D(E,x)+px$ the effective damage function.

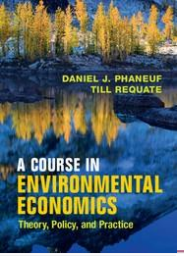
- Joint cost minimization problem:

$$\min_{E,x}\left\{D(E,x)+px+C(E)\right\} \qquad (3.16)$$

- F.O.C.s:

$$-C'(E)=D_E(E,x) \qquad (3.17)$$

$$-D_x(E,x)=p$$



3.2.4 Polluter Pays Principle

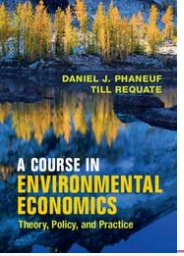
- We see it is optimal that the household engages in some level of defense measure.
- Assume now, the polluter must fully comensate the household for any damage (**The Pollter Pays Principle**).
- Then the household chooses x=0.
- The firm's cost minimization problem is:

$$\min_{E}\left\{C(E)+D(E,0)\right\} \qquad (3.18)$$

- with F.O.C.s:

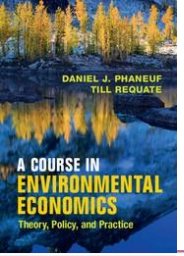
$$-C'(E) = D_E(E,0)$$

- This does not result in an optimal allocation!



3.2.4 Polluter Pays Principle

- Note, however, that the **Polluter Pays Principle (PPP)** results in optimal allocations if the household‘s damage is just D(E), i.e. the household has no means to protect itself agains the externality!



Summary

- The optimal level of pollution is that which equates the marginal social damage of pollution to the marginal cost of its prevention.
- The minimum total abatement cost for any level of pollution occurs when polluters' marginal abatement cost levels are equal.
- Policies that use economic incentives – emission taxes, auctioned and free distribution permit schemes, and subsidies – will generally be preferred to command and control-type policies based on cost effectiveness.
- We have assumed perfect information and our perspective has been static, non-spatial, partial equilibrium, and short run in nature.