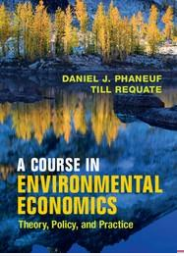


Environmental Economics

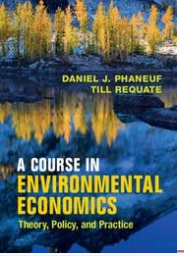
Lecture 4
(Chapter 5 from textbook)

Competitive Output Markets



Competitive Output Markets

- In this chapter we take into account output markets
- By considering firm profits and consumer preferences for the polluting good we can distinguish between engineering-based abatement costs and the gross economic costs that arise from lost profit and consumption benefits through reducing pollution.
- We show that results derived in Ch. 3 for a fixed number of firms continue to hold: optimal abatement policy is still characterized by the marginal abatement cost equals the marginal damage.
- Market based instruments also work fine.
- Taxes and permits also work under market entry.
- Another topic to be investigated are relative standards.



5.1.1 Cost Functions

- The firm's cost function $C(x,e)$ is derived from the following cost minimization problem:

$$C(x,e)=\min_{I_1,\ldots,J_K}\left\{\sum_{k=1}^{K}w_k I_k+\lambda\left[x-f\left(I_1,\ldots,I_K\right)\right]+\mu\left[e-g\left(I_1,\ldots,I_K\right)\right]\right\} \qquad (5.1)$$

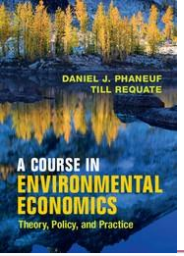
- Where $w_1,\ldots,w_k$ is the vector of factor input prices, and

$x=f\left(I_1,\ldots,I_K\right)$ denotes the output production function,

$x=g\left(I_1,\ldots,I_K\right)$ denotes the emission „production function"

Some of the inputs maybe productive, such as energy input, which at the same time cause pollution.

Other inputs may just be needed to reduce emissions such as lime solution to run a scrubber.



5.1.1 Cost Functions

Case 1

- Assumption 5.1: The cost function $C(x,e)$ is twice differentiable with $C_x(\cdot) > 0$, and for any production level there is an emission level $\hat{e}^x$ such that $C_e(x,\hat{e}^x) = 0$.

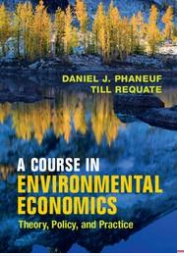
$$C_e(x,e) < 0 \qquad \forall e < \hat{e}^x \tag{5.2}$$

$$C_e(x,e) \geq 0 \qquad \forall e \geq \hat{e}^x$$

- And

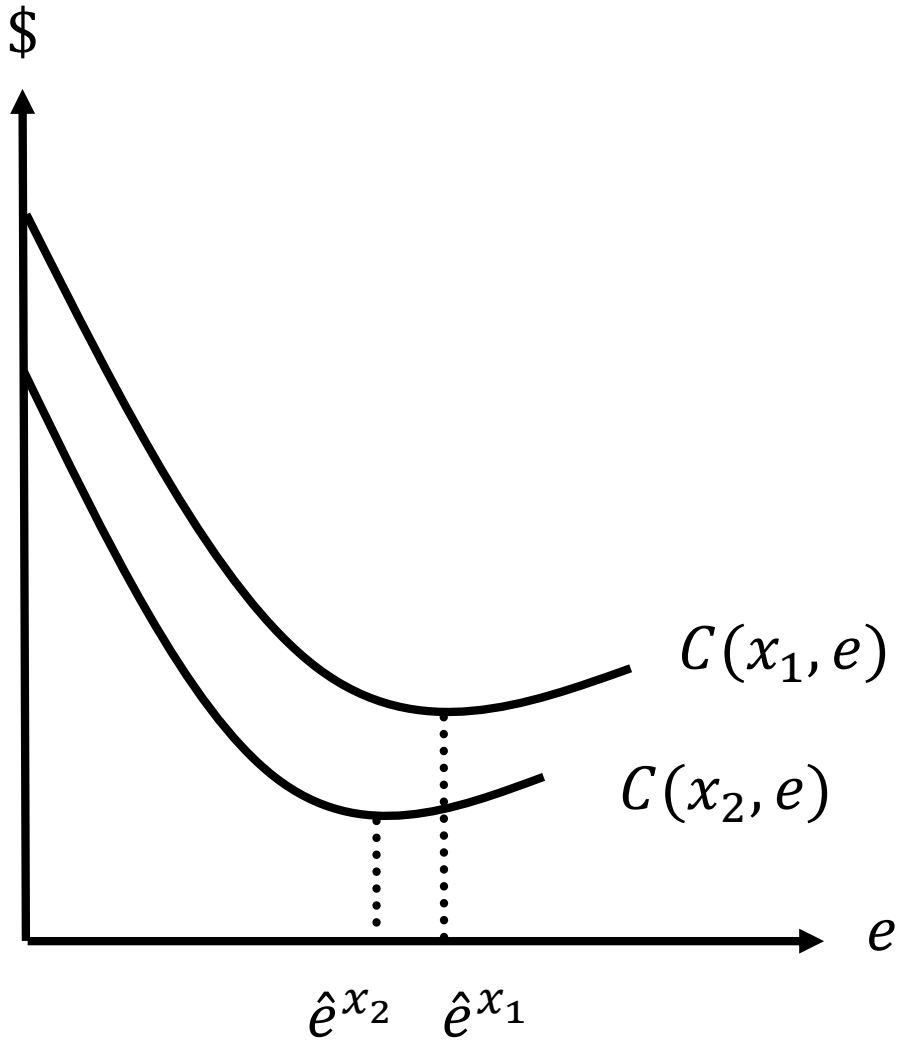
$$C_{xe}(x,e) = C_{ex}(x,e) < 0 \quad \Leftrightarrow \quad -C_{ex}(x,e) > 0, \quad \forall e < \hat{e}^x \tag{5.3}$$

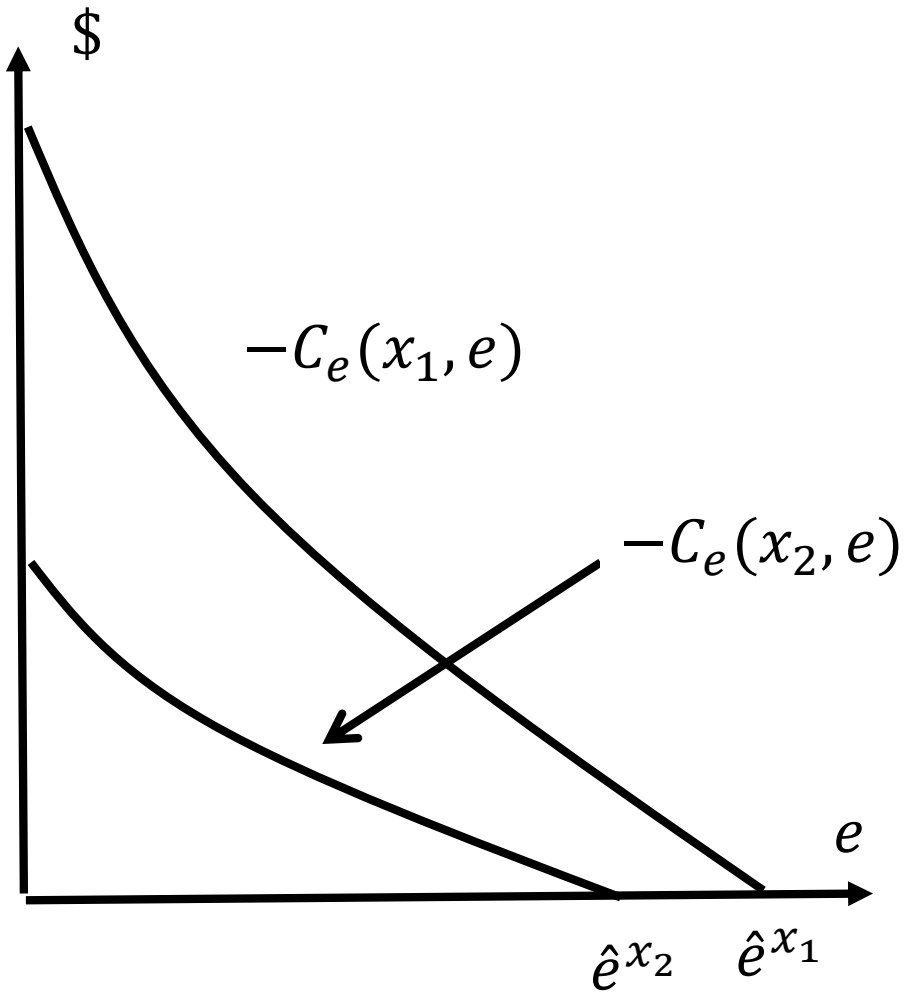
- $C_e(x,\hat{e}^x) = 0$ means that for each output level x there is a cost minimizing emission level $\hat{e}^x$ that results when the emission constraint is not binding due to the absence of environmental regulation.
- Moving emissions below (or above) the optimal unregulated choice for an output level x increase the firm's cost.

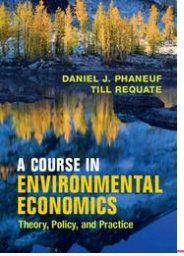


Assumptions on abatement costs

Figure 5.1 Case 1, $x_1 > x_2$







5.1.1 Cost Functions

$$C_{xe}(x,e) = C_{ex}(x,e) < 0 \quad \Leftrightarrow \quad -C_{ex}(x,e) > 0, \quad \forall e < \hat{e}^x \tag{5.3}$$

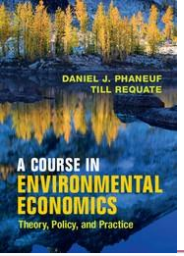
- Interpretation: The marginal cost of production is smaller if the emission level is allowed to rise $C_{xe}(\cdot) < 0$ or equivalently, the marginal abatement cost function shifts up if the output level rises $-C_{ex}(\cdot) > 0$.

- We totally differentiate $C_e(x, \hat{e}^x) = 0$ to obtain:

$$C_{ee}(x, \hat{e}^x)d\hat{e}^x + C_{ex}(x, \hat{e}^x)dx = 0$$

- which we can rearrange:

$$\frac{d\hat{e}^x}{dx} = -\frac{C_{ee}(x,\hat{e}^x)}{C_{ex}(x,\hat{e}^x)} > 0 \tag{5.4}$$



5.1.1 Cost Functions

Case 2

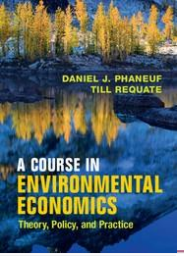
- Assumption 5.2: The cost function $C(x)$ is twice continuously differentiable satisfying $C'(\cdot) > 0$ and $C''(\cdot) \geq 0$, and emissions depend on x directly according to $e = \delta(x)$, where $\delta'(x) > 0$. For some discussion we will use a simplification of the emissions technology in which $\delta(x) = \delta \cdot x$, for $\delta > 0$.

- Under assumption 5.2 the marginal abatement cost function is tied to the firm's profit per unit of output.

- If p is the output price of x the competitive firm´s profit is $\prod = px - C(x)$.

- Adopting the simplification that $e = \delta x$ and differentiating with respect to e we gain:

$$\frac{d\prod}{de} = \frac{p - C'(e/\delta)}{\delta} \qquad (5.5)$$



5.1.1 Cost Functions

- Since $p - C'(x) = 0$ is the condition for profit maximization with no regulation, $p - C'(\hat{e}^x/\delta) = 0$ implicitly defines the unregulated level of pollution.

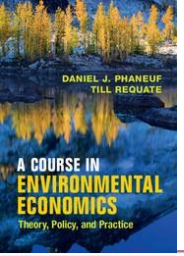
- For $e < \hat{e}^x$ we know that $p - C'(e/\delta) > 0$, since an emission level lower than $\hat{e}^x$ implies the output level is also lower than what is privately optimal for the firm.

- Under Assumption 5.2 the marginal abatement cost function is therefore given by (5.5), where $d\Pi/de > 0$ for $e < \hat{e}^x$.

- Abatement cost here consists in forgone profits!

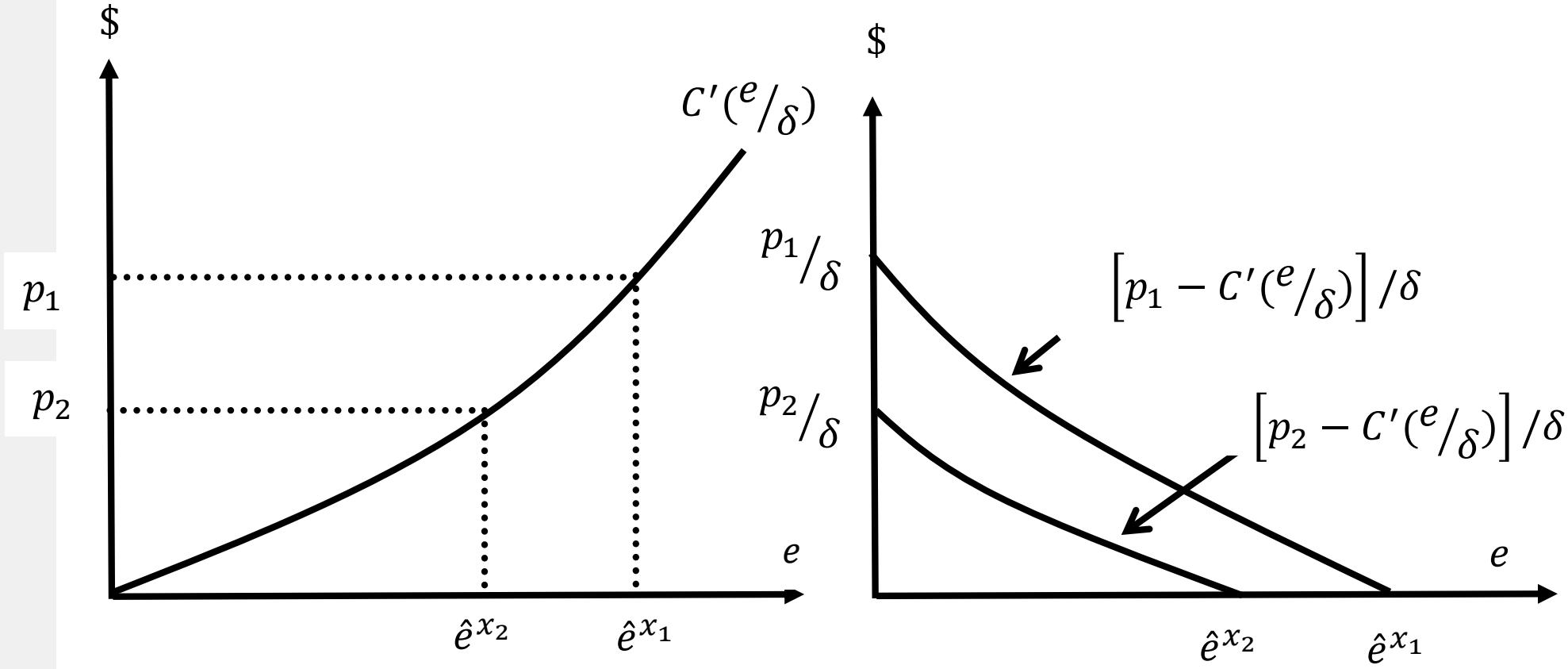
- Moreover, the marginal abatement cost curve is decreasing in e:

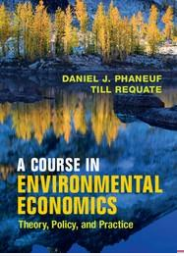
$$\frac{d^2\Pi}{de^2} = -\frac{C''(e/\delta)}{\delta^2} < 0 \qquad (5.6)$$



Assumptions on abatement costs

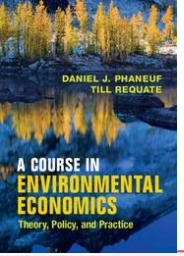
Figure 5.1 Case 2, $x_1 > x_2$





5.1.2 Market Demand

- To derive household´s benefits of consuming x and the damages suffered from pollution we assume quasi-linear preferences: $U^i = u_i(x_i) + z_i - D_i(E)$.
- x_i is the person´s consumption level.
- $u_i(x_i)$ is the sub-utility function from consuming the polluting good.
- z_i is spending on all other goods.
- Maximizing utility subject to the budget constraint $y_i = px_i + z_i$, results in the F.O.C. for x_i : $u_i'(x_i) = p$.
- This defines the inverse demand (marginal willingness to pay) for x function for person i as: $p_i(x_i) = u_i'(x_i)$.



5.1.2 Market Demand

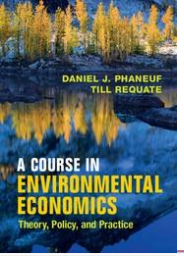
- The money-metric gross benefit the consumer enjoys from consuming the polluting good is:

$$\int_0^{x_i} p_i(t)\,dt = u_i(x_i) \qquad (5.7)$$

- To measure the market benefits, let $X = \sum_{i=1}^{I} x_i$ be the aggregate consumption level and define $P(X)$ as the market inverse demand curve.

- The money-metric benefit to all households from consuming the polluting good is the area under the market inverse demand function.

- Thus the damage function $D(E)$ and the market inverse demand function $P(X)$ allow us to characterize the benefits and damages to society, brought about by production and consumption of the polluting good.



5.1.3 Welfare and Social Optimum

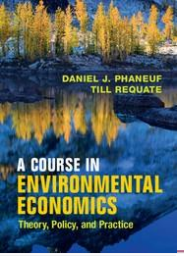
Case 1

- Given our assumptions, the net benefits to society from the polluting good is the difference between utility benefits of its consumption and the private and environmental cost of production.

$$W\left(x_1,\ldots,x_J,e_1,\ldots,e_J\right) \equiv \int_0^{X=\sum x_j} P(t)dt - \sum_{j=1}^{J} C^j\left(x_j,e_j\right) - D(E) \quad (5.8)$$

- where the subscripts $j = 1, \ldots, J$ index the specific firm.

- $E = \sum_{j=1}^{J} e_j$ is the aggregate emissions level.



5.1.3 Welfare and Social Optimum

$$W\left(x_1,...,x_J,e_1,...,e_J\right) \equiv \int_0^{X=\sum x_j} P(t)dt - \sum_{j=1}^{J} C^j\left(x_j,e_j\right) - D(E) \qquad (5.8)$$

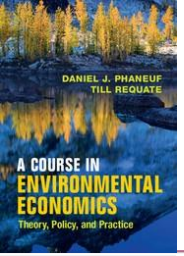
- The F.O.C.s for the optimum are:

$$P(X) = C^j_{x_j}\left(x_j,e_j\right),$$

$$D'(E) = -C^j_{e_j}\left(x_j,e_j\right) \qquad j = 1,...,J \qquad (5.10)$$

- The first eq. gives the standard micro theory result that at the social optimum the marginal cost of production should be equal to the marginal benefit of consumption.

- The second eq. confirms that for each firm the marginal abatement cost should be equal to its marginal social damage.



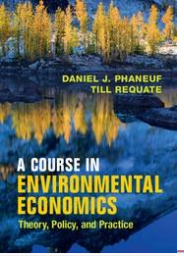
5.1.3 Welfare and Social Optimum

Case 2

- If the technologies are such that emissions are directly related to output, the net benefits are:

$$W(x_1,\ldots,x_J) \equiv \int_0^{X=\sum x_j} P(t)dt - \sum_{j=1}^{J} C_j(x_j) - D(E) \qquad (5.9)$$

where $E = \sum_{j=1}^{J} \delta_j(x_j)$.



5.1.3 Welfare and Social Optimum

- The net benefits are

$$W(x_1,...,x_J) \equiv \int_0^{X=\sum x_j} P(t)dt - \sum_{j=1}^{J} C_j(x_j) - D(E) \qquad (5.9)$$

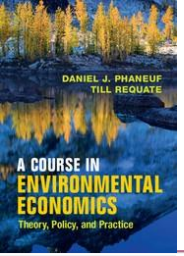
- where $E = \sum_{j=1}^{J} \delta_j(x_j)$

- Here, only the x_j´s are choice variables, implying the F.O.C. is:

$$P(X) = C_j'(x_j) + D'(E)\delta_j'(x_j) \qquad j = 1,...,J \qquad (5.11)$$

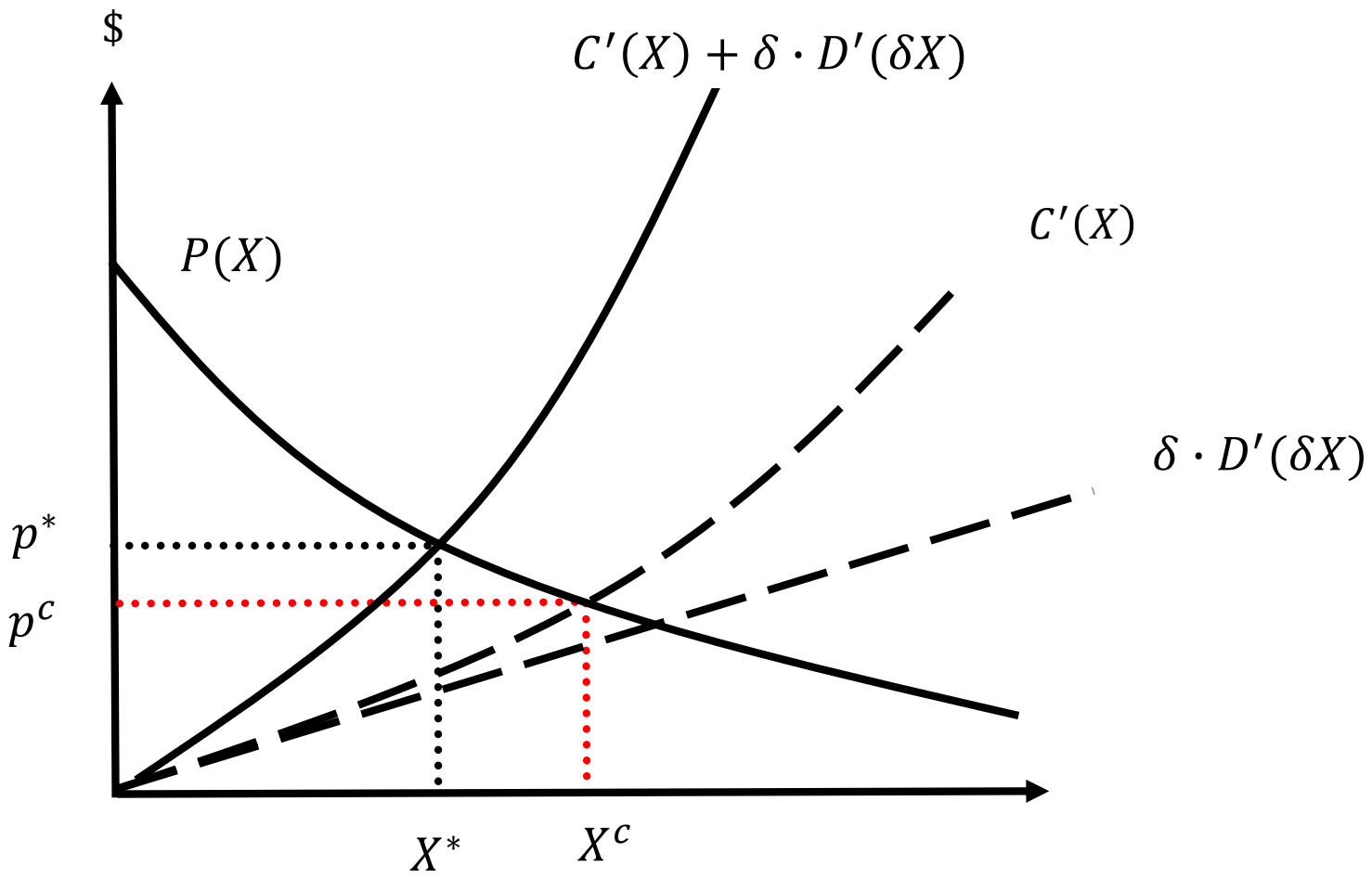
- For the special case of identical firms with linear emission functions $e = \delta x$, we can develop further intuition graphically.

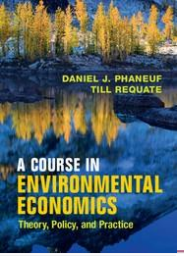
$$P(X) = C'(X) + \delta D'(\delta X) \qquad (5.12)$$



5.1.3 Welfare and Social Optimum

Figure 5.2 Social Optimum

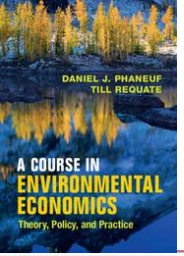




5.2 Environmental Policy Instruments

An environmental regulator can achieve the socially optimal allocation of pollution using

- Emission taxes,
- Subsidies,
- Auctioned permits,
- or freely distributed tradable permits.



5.2.1 Taxes

Case 1

- Consider a competitive firm´s choices when faced with an emission tax τ and abatement is possible.
- The profit for firm j is:

$$\prod_j \left(x_j, e_j\right) = px_j - C^j\left(x_j, e_j\right) - \tau e_j \qquad (5.13)$$

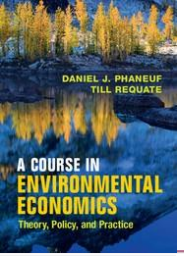
- Where p is the market price of x that is taken given.

- Firm chooses its output and emission level based on F.O.C.:

$$p = C^j_{x_j}\left(x_j, e_j\right) \qquad (5.14)$$

$$\tau = -C^j_{e_j}\left(x_j, e_j\right)$$

- Competitive firm chooses output to set its marginal cost equal to the market price.
- Also firm choses its emission so that its marginal abatement cost is equal to tax level.



5.2.1 Taxes

Case 2

- Abatement is not possible.
- The optimal tax rate is set equal to the marginal damage function.

- The firm´s profit is given by:

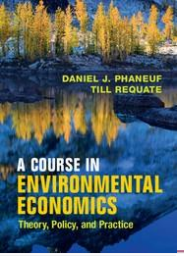
$$\prod_j (x_j) = p x_j - C_j(x_j) - \tau \delta_j x_j \qquad (5.15)$$

- F.O.C. is: $p = C_j'(x_j) + \tau \delta_j$

- If we set $\tau = D'(E^*)$ and assume the competitive market clears, each firm j behaves according to

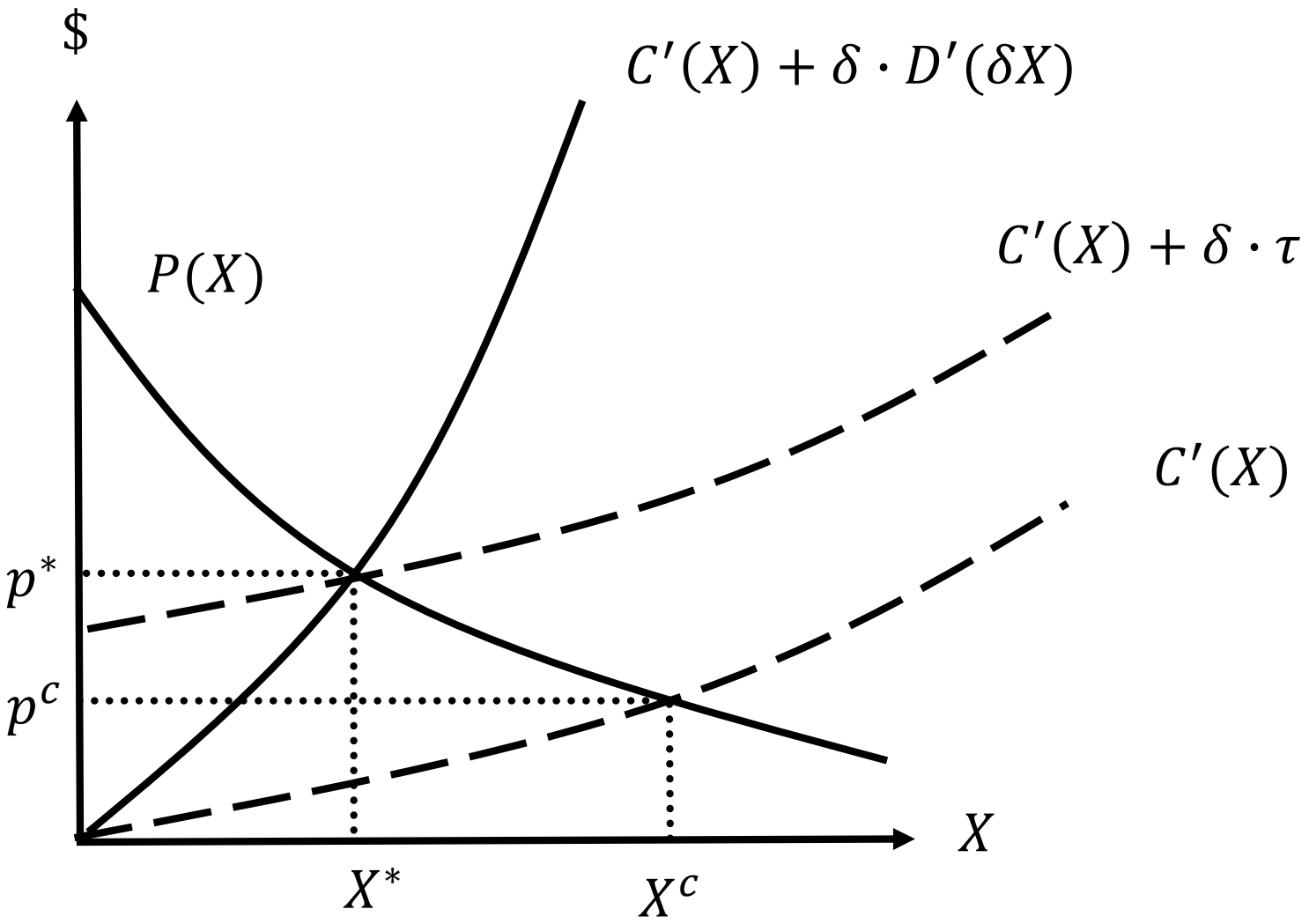
$$P(X) = C_j'(x_j) + \delta_j \tau = C_j'(x_j) + \delta_j D'(E^*), \qquad j = 1,...,J \qquad (5.16)$$

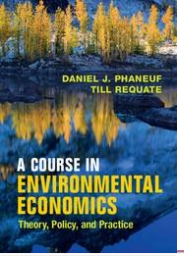
- For each firm the optimal production level equates the marginal benefit of an additional unit with the marginal cost consisting of private and external components.



5.2.1 Taxes

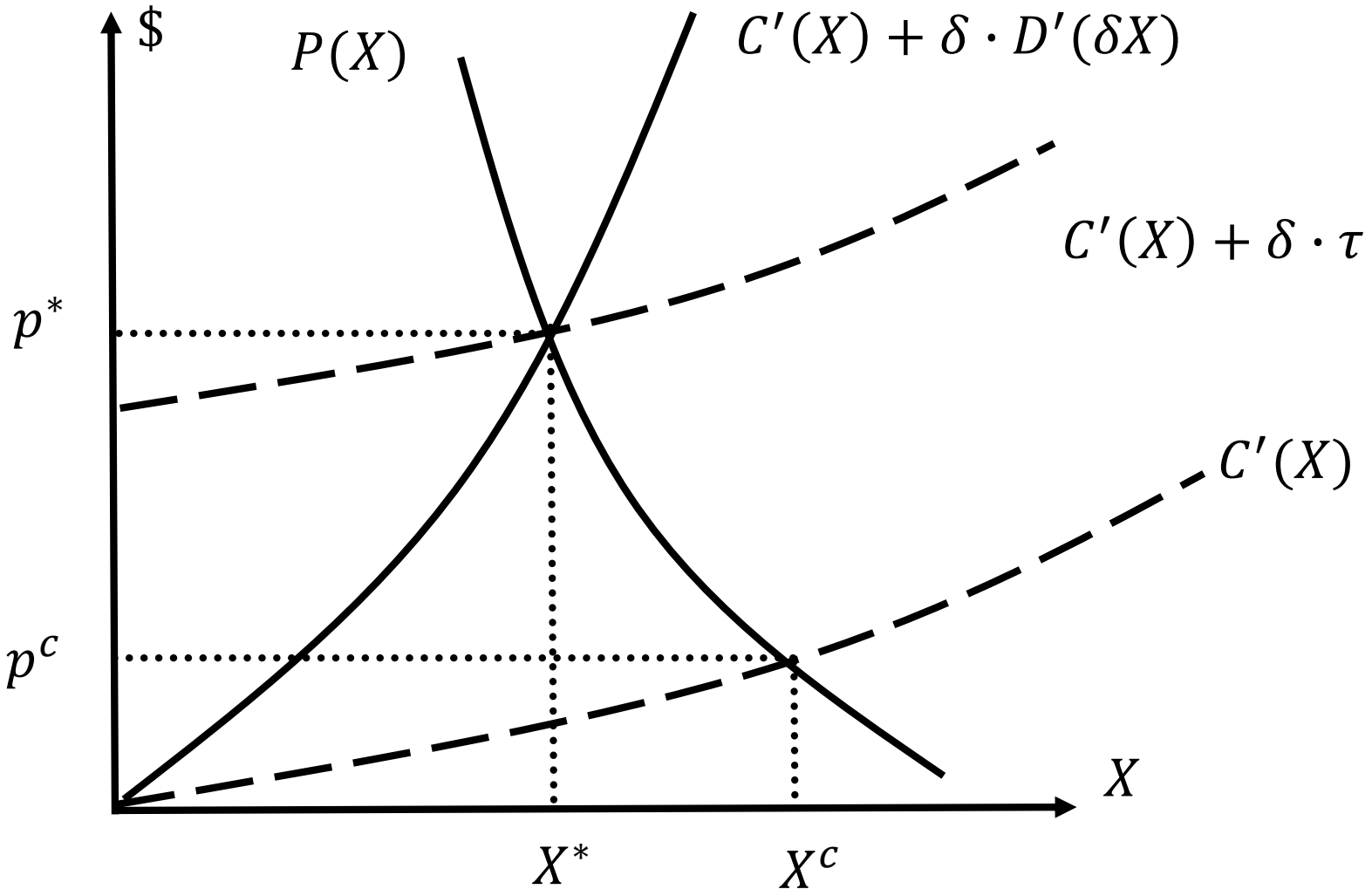
Figure 5.3 Optimal environmental taxes

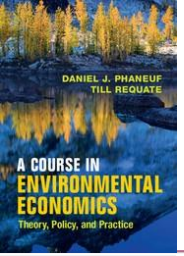




5.2.1 Taxes

Figure 5.3 Optimal environmental taxes





5.2.1 Taxes

- comparative statics -

Case 2

- The profit maximizing condition for each of the J firms is:

$$P(X) = C'(x) + \delta\tau, \quad \text{where } X = x \bullet J$$

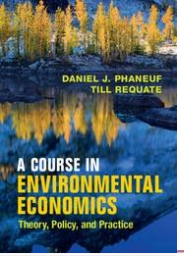
- By implicitly differentiating the profit maximization condition with respect to τ we obtain:

$$\left[P'(X) \bullet J - C''(x)\right]\frac{dx}{d\tau} = \delta \qquad (5.17)$$

- From which we can solve for and sign the comparative static effect as

$$\frac{dx}{dt} = \frac{\delta}{P'(X) \bullet J - C''(x)} < 0 \qquad (5.18)$$

$$\frac{dX}{d\tau} = J\frac{dx}{d\tau} < 0 \qquad \text{since } P'(x) < 0 \text{ and } C''(x) \geq 0$$



5.2.1 Taxes

- comparative statics -

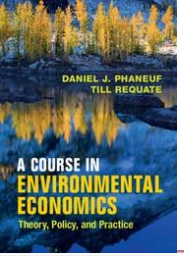
- With $E = \delta \cdot X$ we can see that:

$$\frac{dE}{d\tau} = \delta \frac{dX}{d\tau} = \frac{J \bullet \delta^2}{J \bullet P'(X) - C''(x)} < 0 \qquad (5.19)$$

- Finally, since $p = P(X)$ is the market price of the polluting good, we can state the relationship between equilibrium price level and emission tax as

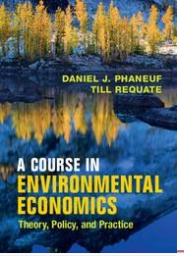
$$\frac{dp}{d\tau} = P'(X)\frac{dX}{d\tau} > 0 \qquad (5.20)$$

- As intuition suggests, the output and emission levels decrease when emission tax is introduced or increased, and the market price for the polluting good increases.



5.2.1 Taxes

- Less obvious is that the consumers' share of the tax incidence depends on how elastic the demand curve is.
- If $P'(X)$ is small in absolute magnitude (demand is elastic) the price increase will be comparatively small.
- Tax incidence will be borne primarily by firms.
- If $P'(X)$ is large in absolute magnitude (demand is inelastic) the price increase will be comparatively large.
- Consumers have few substitutes.
- Tax incidence will be borne primarily by consumers.
- Industry will be comparatively unaffected.



5.2.1 Taxes

- comparative statics -

Case 1

- Abatement is possible.
- We assume identical firms, each of which maximizes profit according to the F.O.C.s:

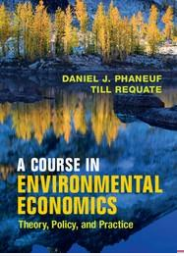
$$P(X) = C_x(x,e) \qquad (5.21)$$

$$\tau = -C_e(x,e)$$

- When we implicitly differentiate both conditions with respect to τ we obtain:

$$P'(X) \bullet J \bullet \frac{\partial x}{\partial \tau} = C_{xx}(x,e) \bullet \frac{\partial x}{\partial \tau} + C_{xe}(x,e) \bullet \frac{\partial e}{\partial \tau}, \qquad (5.22)$$

$$1 = -C_{xe}(x,e)\frac{\partial x}{\partial \tau} - C_{ee}(x,e)\frac{\partial e}{\partial \tau}$$



5.2.1 Taxes

- comparative statics -

Case 1

- Abatement is possible.
- We assume identical firms, each of which maximizes profit according to the F.O.C.s:

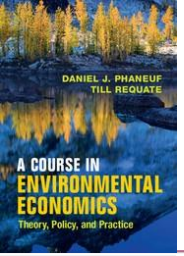
$$P(X) = C_x(x,e) \qquad (5.21)$$

$$\tau = -C_e(x,e)$$

- When we implicitly differentiate both conditions with respect to τ we obtain:

$$P'(X) \cdot J \cdot \frac{\partial x}{\partial \tau} = C_{xx}(x,e) \cdot \frac{\partial x}{\partial \tau} + C_{xe}(x,e) \cdot \frac{\partial e}{\partial \tau} \qquad (5.22)$$

$$1 = -C_{xe}(x,e)\frac{\partial x}{\partial \tau} - C_{ee}(x,e)\frac{\partial e}{\partial \tau}$$



5.2.1 Taxes
- comparative statics -

in matrix form:

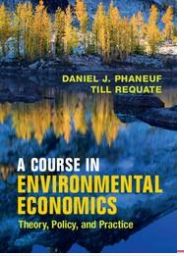
$$\begin{bmatrix} P'(X)\bullet J - C_{xx}(x,e) & -C_{xe}(x,e) \\ -C_{xe}(x,e) & -C_{ee}(x,e) \end{bmatrix} \begin{bmatrix} \partial x / \partial \tau \\ \partial e / \partial \tau \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{5.23}$$

Solving this system using Cramer´s Rule results in

$$\frac{\partial x}{\partial \tau} = \frac{C_{xe}(x,e)}{-J\bullet P'(X)\bullet C_{ee}(x,e) + C_{xx}(x,e)\bullet C_{ee}(x,e) - C_{xe}^2(x,e)} < 0 \tag{5.24}$$

and

$$\frac{\partial e}{\partial \tau} = \frac{P'(X)\bullet J - C_{xx}(x,e)}{-P'(X)\bullet J\bullet C_{ee}(x,e) + C_{xx}(x,e)\bullet C_{ee}(e,x) - C_{xe}^2(x,e)} < 0 \tag{5.25}$$



5.2.1 Taxes

- comparative statics -

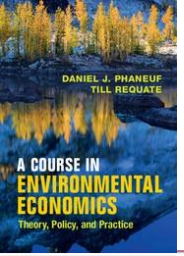
- Interestingly, we can see from (5.24) that a tax increase decreases output more when emissions and output are relatively more complementary.

- From our assumptions on cost and demand functions, the denominator in both (5.24) and (5.25) is positive and the numerators are negative. From these it follows that:

$$\frac{\partial X}{\partial \tau} = J \bullet \frac{\partial x}{\partial \tau} < 0 \qquad (5.26)$$

$$\frac{\partial E}{\partial \tau} = J \bullet \frac{\partial e}{\partial \tau} < 0$$

$$\frac{\partial p}{\partial \tau} = P'(X) \bullet \frac{\partial X}{\partial \tau} > 0$$



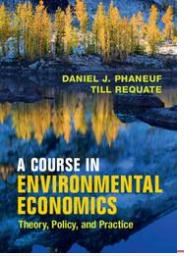
Proposition 5.1

Under the assumptions of the model, the introduction (or increase) of an emissions tax leads to:

(1) a decrease in both individual firms‘ and aggregate emission levels;

(2) a decrease in individual firms‘ and aggregate output levels; and

(3) an increase in the output price.



5.2.2 Permits and other instruments

- Instead of charging an emission tax the regulator could make available a number of pollution permits $L = E^*$, either by auctioning or distributing them freely to firms and allowing exchanges.

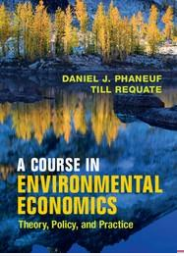
- If a permit market is well functioning, there is a market clearing price $\sigma(L)$ for each level of permits L.

- If firms are permit market price takers, their profit maximizing behavior leads to identical conditions as in the emission fee case.

- The F.O.C. are:

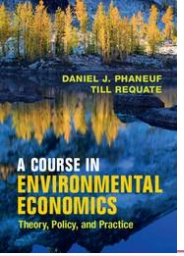
$$p = C^j_{xj}\left(x_j, e_j\right) \qquad (5.27)$$

$$\sigma = -C^j_{ej}\left(x_j, e_j\right), \qquad j = 1,\ldots,J$$



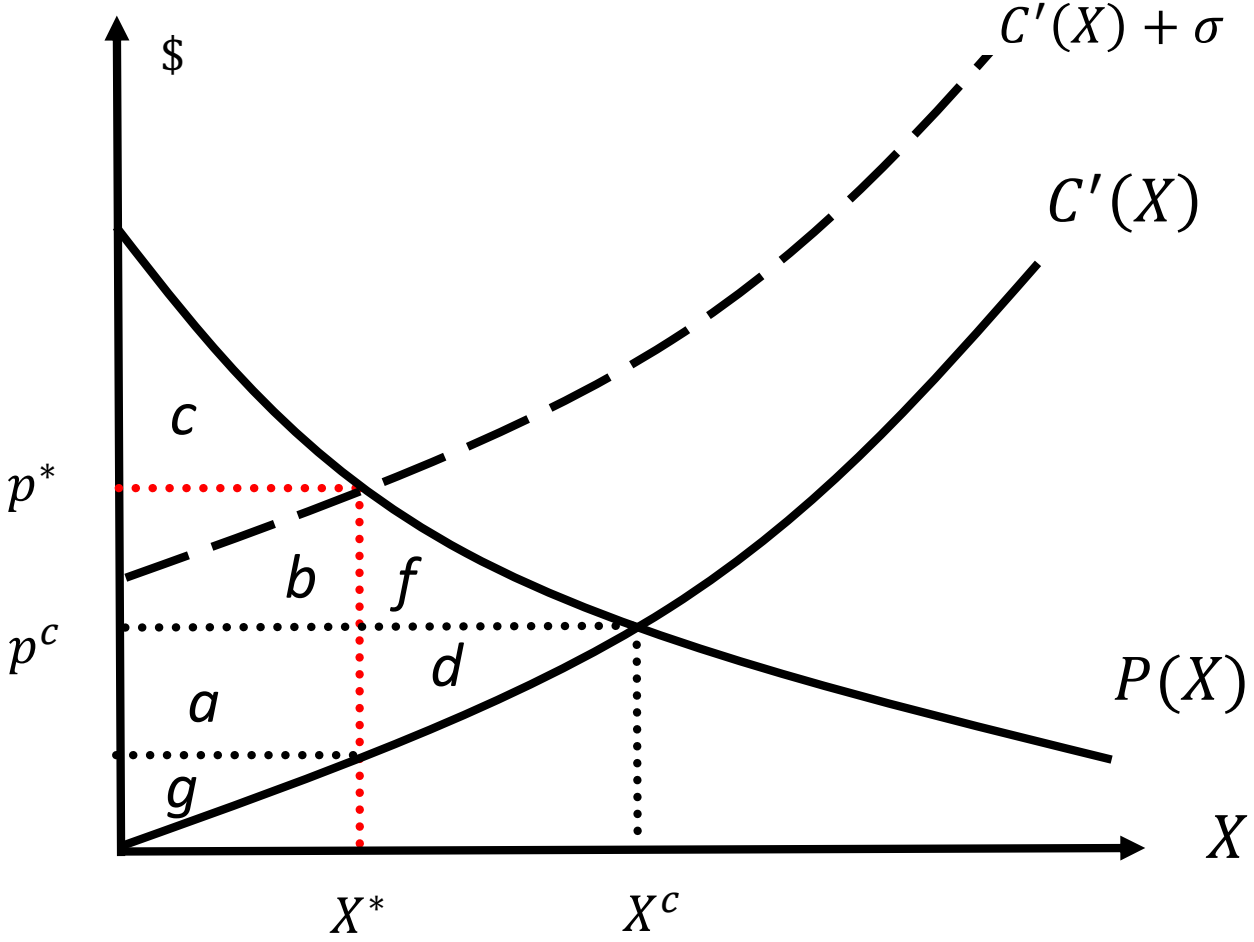
5.2.2 Permits and other instruments

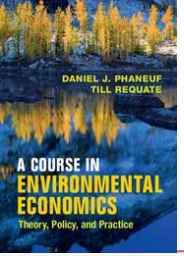
- By optimally choosing the level of permits, the regulator can implement the first best.
- By choosing $L = E^*$ the regulator can assure the resulting permit price will be $\sigma(L) = \sigma(E^*) = D'(E^*)$, and the output price equilibrates to $p = P(X^*)$.
- Similarly, one can also show for the case of freely distributed permits and subsidies that properly chosen aggregate permit or subsidy levels can achieve the first-best, short run outcome.
- **Auctioned and freely distributed permits are fully equivalent here**, outside the obvious property right differences. This means that under freely distributed permits, the output price change is equivalent to what would occur under auctioned permits.



5.2.2 Permits and other instruments

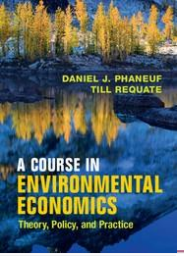
Figure 5.4 Distribution of rents in auctioned versus freely distributed permits



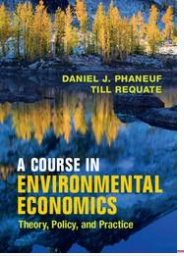


5.2.2 Permits and other instruments

- Consider Figure 5.4:
- Under auctioned permits, by pollution control, producer‘s rent shrinks from *a+d+g* to *g.*
- Under free permits, by pollution control, producer‘s rent increases from *a+d+g* to *a+b+g.*
- In both cases, consumer‘s benefit shrink from *c+b+f* to *c*.

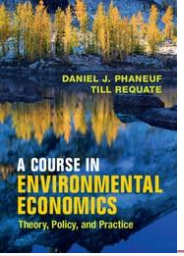


Standards Reconsidered: Generation Performance Standards



5.3 Generation Performance Standards

- Theoretical discussions on environmental standards usually focus on an absolute emission standard, in which firms' emissions may not exceed an administratively set level.
- Implementation and enforcement of this type of standard, however, requires regular measurement of emissions from the polluting sources.
- In this section we examine *relative standards*, a class of policy tools in which polluting sources are regulated based on the concentration of a pollutant in some measurable output.
- Use of relative standards is common in both Europe and the United States.



5.3 Generation Performance Standards

- Consider a regulation based on emissions per unit of output. Output and emission levels must comply with

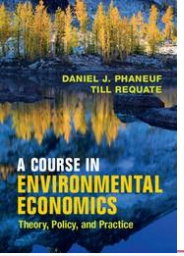
$$e/x \leq \alpha \qquad (5.34)$$

- with α as policy variable.

- In Case 2, Eq. (5.34) is satisfied whenever $\alpha \geq \delta(x)$; conversely, if $\alpha < \delta(x)$ the firm can only comply with the standard by shutting down.

- The analysis is more interesting for Case 1, when abatement possibilities exists. If (5.34) is binding, profit for a single competitive firm is given by

$$\prod(x) = px - C(x, \alpha x) \qquad (5.35)$$



5.3 Generation Performance Standards

- Profit function for a single competitive firm is given by:

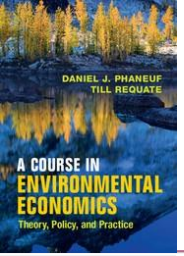
$$\prod(x) = px - C(x, \alpha x) \qquad (5.35)$$

- Where substituting $e = \alpha x$ implies that x is the only choice variable.

- The F.O.C. for profit maximization is:

$$p = C_x(x, \alpha x) + \alpha C_e(x, \alpha x) \qquad (5.36)$$

- The solution to this problem is the firm´s output supply function, which we denote $x(\alpha)$ to make explicit its dependence on α.

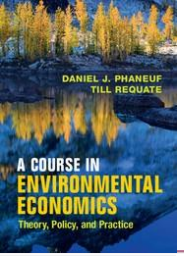


5.3 Generation Performance Standards

- Suppose the regulator aims to establish an emission goal for the firm of $e = \bar{e}$, and that the government has knowledge of the firm's behavior as summarized by $x(\alpha)$.
- Regulator aims to establish an emission goal for the firm of $e = \bar{e}$.
- Regulator can set $\alpha = \bar{e}/x(\alpha)$.
- For comparison consider an absolute standard in which the regulator directly sets $e = \bar{e}$ to achieve the same outcome.

$$\prod(x,\bar{e}) = px - C(x,\bar{e}) \qquad (5.37)$$

- The firm's output supply $x(\bar{e})$ is implicitly defined by F.O.C $p = C_x(x,\bar{e})$.



5.3 Generation Performance Standards

- If instead the regulator sets emission level with the relative standard $\bar{e} = \alpha x(\alpha)$, by (5.36) we get the condition:

$$p - \alpha C_e\left(x(\alpha),\bar{e}\right) = C_x\left(x(\alpha),\bar{e}\right) > p \qquad (5.38)$$

- where inequality follows from the positive marginal abatement cost curve.

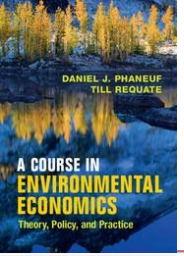
- Comparing (5.38) with the F.O.C. under the absolute standard we obtain:

$$C_x\left(x(\alpha),\bar{e}\right) > C_x\left(x(\bar{e}),\bar{e}\right) \qquad (5.39)$$

- It follows that $x(\alpha) > x(\bar{e})$.

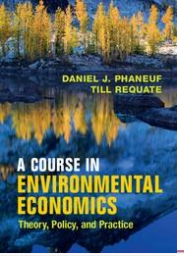
$$C\left(x(\alpha),\bar{e}\right) > C\left(x(\bar{e}),\bar{e}\right)$$

$$-C_e\left(x(\alpha),\bar{e}\right) > -C_e\left(x(\bar{e}),\bar{e}\right) \qquad (5.40)$$



Proposition 5.2

- *Suppose an environmental regulator sets an emission goal of $\bar{e}$ and uses a relative standard α to obtain it.*
- *If there is a single firm or J identical firms, the policy will lead to higher output, higher total costs, and higher marginal abatement cost relative to a comparable absolute standard.*

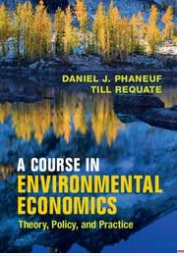


Proposition 5.2

- *Under the relative standard, a polluting firm can achieve compliance with the regulation not only through the direct reduction of emissions, but also by diluting emissions via increased output.*

- *The use of relative standard therefore is preferred only in a second-best setting in which an absolute standard or more efficient instrument cannot be implemented.*

- *Suppose such constraint exist, and given a known damage function, the regulator must choose a relative standard to maximize social welfare in presence of a single polluting firm.*



5.3 Generation Performance Standards

- Maximizing social welfare:

$$W(\alpha) = \int_0^{x(\alpha)} P(t)dt - C\left(x(\alpha), \alpha x(\alpha)\right) - D\left(\alpha x(\alpha)\right) \tag{5.41}$$

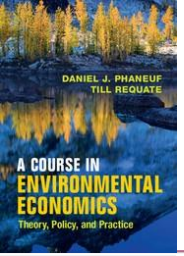
- Differentiating with respect to α leads to:

$$\left[P - C_x(\bullet) - \alpha C_e(\bullet)\right] x'(\alpha) - C_e(\bullet)x - D'(\bullet)\bullet\left(x + ax'(\alpha)\right) = 0 \tag{5.42}$$

- Given the F.O.C. $p = C_x(x, \alpha x) + \alpha C_e(x, \alpha x)$ the term in square brackets is zero.

- Rearranging the remaining terms to isolate the marginal abatement cost function we obtain:

$$-C_e(x,e) = \frac{x + \alpha x'(\alpha)}{x} D'(e) \tag{5.43}$$

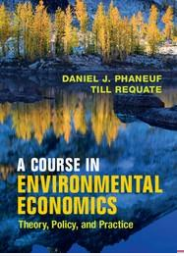


5.3 Generation Performance Standards

- Recall that $x'(\alpha)$ summarizes the firm's output reaction to the policy variable, and note that its sign determines whether the marginal abatement cost exceeds or falls below marginal damages in (5.43).

- While the sign of $x'(\alpha)$ is indeterminate in general, it is intuitive to suppose that $x'(\alpha) > 0$, so that output expands when the standard is relaxed.

- If this is the case, the optimal policy in an environment that requires use of a *relative standard leads to marginal abatement cost which exceed marginal social damage*, and as such emissions that are lower than socially optimal.



5.3 Standards reconsidered – type II

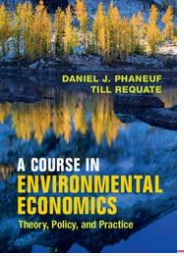
- A second type of relative standard restricts the amount of a particular pollutant to a total volume of effluent.
- From a joint production process given by a generalization of the emission technology we gain:

$$(e_1, e_2) = h(I_1, ..., I_k) \tag{5.44}$$

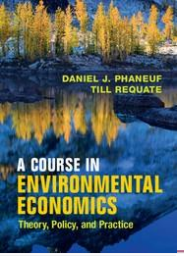
- Suppose that pollutant 1 is subject to regulation relative to total emission of both pollutants. In this case a relative standard can be defined according to:

$$\frac{e_1}{e_1 + e_2} \leq \alpha \tag{5.45}$$

- A relative standard leads to an inefficient result, even if firms are identical.

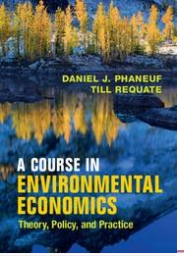


Long run optimality of environmental policy instruments (market entry)



5.4 Long run optimality of environmental policy instruments

- Firms may enter and exit the market.
- Basic micro theory:
  - Under perfect conditions, technologically identical firms enter or exit the market until profits are driven to zero.
  - All firms produce at the minimum point on their long run average cost curve.
  - If firms have non-zero fixed costs and strictly convex costs functions, the socially optimal number of firms is endogenously determined.
  - In what follows we maintain these traditional assumptions while considering the long run impact of environmental policy on a competitive industry.



5.4.1 Long Run Social Optimum

- Define the cost function for the J identical firms as consisting of both fixed and variable costs:

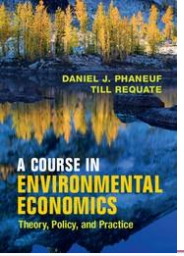
$$C(x,e)=\begin{cases} VC(x,e)+F & x,e\neq 0 \\ 0 & x,e=0 \end{cases} \tag{5.46}$$

- where F is the fixed cost of entry and $VC(x,e)$ denotes variable costs.

$$W(x,e,J)=\max_{x,e,J}\int_0^{x\bullet J} P(t)dt - J\bullet C(x,e) - D(e\bullet J) \tag{5.47}$$

- where total output is $X=xJ$ and the total emission is $E=eJ$.

- In the long run, social welfare depends on firms‘ output and emission levels as well as the number of firms.



5.4.1 Long Run Social Optimum

- The F.O.C. implicitly define the social optimum (x^*, e^*, J^*):

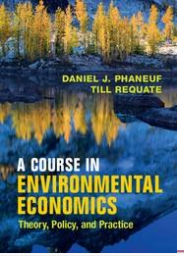
$$P(X^*) = C_x(x^*, e^*)$$
$$D'(E^*) = -C_e(x^*, e^*) \qquad (5.48)$$
$$P(x^*)x^* = C(x^*, e^*) + D'(E^*)e^*.$$

- Rearranging the last F.O.C. slightly we obtain:

$$P(X^*) = \frac{C\left(x^*, e^*\right) + D'\left(E^*\right)e^*}{x^*} \qquad (5.49)$$

- Firms should enter or exit the market until the market price reaches the minimum of the average social cost curve.

- Social cost include the private production costs and the public environmental costs of a unit of the good.

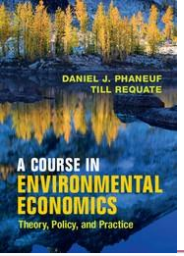


5.4.2 Standards

- If the number of firms is determined endogenously, emission standards fail to obtain the social optimum when firms are identical.
- Regulator aims to implement the optimal emission level E^* by setting an emission standard $e = e^*$.
- $e^* = E^*/J^*$, where J^* is the optimal number of firms in the long run.
- Firm choose according to F.O.C.: $p = C_x(x, e^*)$.
- $\hat{J}$ and $\hat{x}$ are implicitly defined by:

$$P\left(\hat{x}\hat{J}\right) = C_x\left(\hat{x}, e^*\right) \qquad (5.50)$$

$$P\left(\hat{x}\hat{J}\right)\hat{x} - C\left(\hat{x}, e^*\right) = 0$$



5.4.3 Taxes

- If firms are subject to an emission tax, it is straightforward to see that the long run social optimum can be achieved by setting the emission equal to the Pigouvian level:

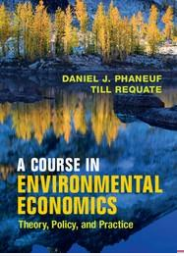
$$\tau = D'(E^*)$$

- Each identical firm's profit function $\prod px - C(x,e) - \tau e$
- F.O.C.s:
- $p = C_x(x,e)$
- $\tau = -C_x(x,e)$

- In the long run, firms enter the market until profits are zero

$$px - C(x,e) - \tau e = 0 \qquad (5.53)$$

- All of these are equivalent to the social optimum conditions when we substitute $p = P(X)$ and $\tau = D'(E^*)$.



5.4.4 Auctioned and Freely Distributed Permits

- Rather than charging an emission tax the regulator could instead auction off a quantity of transferable permits $L = E^*$, where E^* is the socially optimal level of emissions.

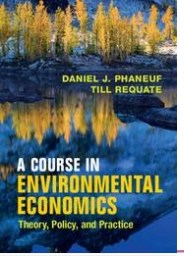
- The long run market equilibrium with an endogenous number identical of firms and price for permits σ is described by:

$$P(xJ) = C_x(x,e) \qquad (5.54)$$

$$\sigma = -C_e(x,e)$$

$$P(xJ)x - C(x,e) - \sigma e = 0$$

- Where $eJ = L = E^*$ permits are available.



5.4.4 Auctioned and Freely Distributed Permits

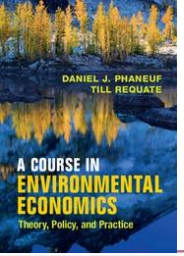
- Since the aggregate factor demand for permits is strictly decreasing in the number of permits, a unique market price for permits exist such that

$$\sigma = -C_e\left(x^*, e^*\right) = D'\left(E^*\right) \qquad (5.55)$$

- Total demand for permits equals total supply.

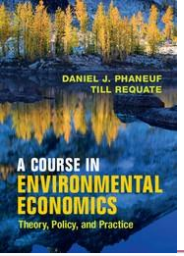
- Unsurprisingly, auctioning off the optimal number of permits leads to the long run socially optimal outcome in a manner quite similar to the emission tax case.

- Auctioned permits and emission taxes can be difficult to implement politically because they involve transfers from the industry to the regulating authority.



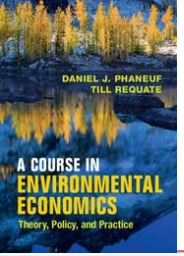
5.4.5 Standards and Subsidies

- By contrast: Emission standards and subsidies induce excessive market entry!
- So are not am optimal instrument to deal with market entry!

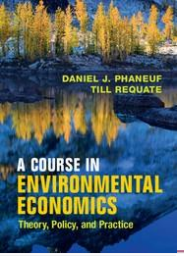


Summary

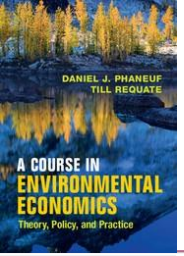
- In the short run when the number of firms is fixed, all of our economic incentive policies can implement first-best.
- Command and control policies and relative standards lead to higher abatement costs for a similar level of pollution reduction in the more general model.
- With respect to long run optimality, absolute standards fail even in the identical firm case.
- Freely distributed permits function similarly to taxes and auctioned permits in the long run, though they have different equity characteristics.



Non-Competitive Output Markets (Chapter 6 from book chapter)


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A COURSE IN
ENVIRONMENTAL
ECONOMICS
Theory, Policy, and Practice

Monopoly



6.1 Monopoly

- Case 2: Pollution can only be reduced by reducing output.
- Assumption: Pollution is proportional to output $E = \delta X$.

- Monopolist's profit maximization problem given the emission tax τ:

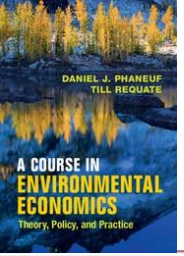
$$\max_X \Pi(X) = P(X)X - C(X) - \tau E \qquad (6.1)$$
$$= P(X)X - C(X) - \tau\delta X,$$

where $P(X)$ is the market inverse demand curve.

- Capital letter for output and emissions to stress that the firm and industry are equivalent.

- FOC:

$$P'(X)X + P(X) = C'(X) + \tau\delta. \qquad (6.2)$$



6.1.1 Taxation when abatement is not possible

$$\max_X \Pi(X) = P(X)X - C(X) - \tau E \qquad (6.1)$$
$$= P(X)X - C(X) - \tau\delta X,$$

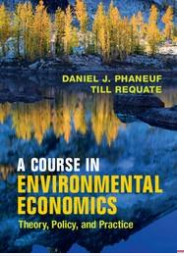
$$P'(X)X + P(X) = C'(X) + \tau\delta. \qquad (6.2)$$

- Differenting (6.2) with respect to τ yields:

$$\left[P''(X^m)X^m + 2P'(X^m) - C''(X^m)\right]\frac{dX^m}{d\tau} = \delta, \qquad (6.3)$$

- Monopolist‘s quantity response to changes in tax rate:

$$\frac{dX^m}{d\tau} = \frac{\delta}{P''(X^m)X^m + 2P'(X^m) - C''(X^m)}. \qquad (6.4)$$

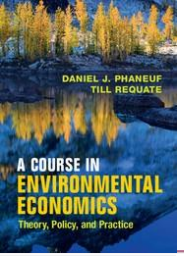


Assumption 6.1

- The inverse demand function $P(X)$is decreasing in X so that $P'(X) < 0$.
- To sign (6.4) we assume

$$\frac{P''(X)}{P'(X)} X > -1. \qquad (6.5)$$

- This standard assumption on preferences states that the inverse demand function is not too convex.
- Monopolist‘s SOC‘s are satisfied.
- We see that $dX/d\tau$ is negative and so an increase in the tax rate causes firms to decrease its output.



6.1.1 Tacation when abatement is not possible

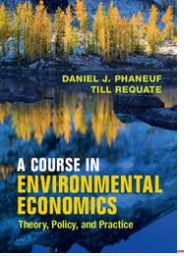
- The regulator‘s objective in general is to maximize the net consumption benefit from X, taking into account the costs to the firm and environmental damage.

- First best outcome X* is the solution to:

$$\max_X \int_0^X P(t)dt - C(X) - D(\delta X), \qquad (6.6)$$

with FOC :

$$P(X^*) = C'(X^*) + \delta D'(\delta X^*). \qquad (6.7)$$



6.1.1 Taxation when abatement is not possible

- Second best solution:
  Selecting a taxrate that maximizes welfare, conditional on the firm‘s optimal response

$$W(\tau) = \int_0^{X^m(\tau)} P(t)dt - C(X^m(\tau)) - D(\delta X^m(\tau)), \qquad (6.8)$$

- Differentiating with respect to τ we obtain

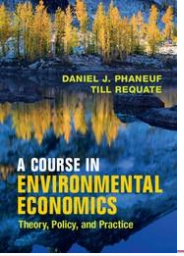
$$\left[P(X^m) - C'(X^m) - \delta D'(\delta X^m)\right] \times \frac{dX^m}{d\tau} = 0. \qquad (6.9)$$

recall from (6.2)

- $P(X^m) - C'(X^m) = \tau\delta - P'(X^m)X^m$

- It follows that we can get the first best by setting:

$$\tau = D'(\delta X^m) + \frac{P'(X^m)X^m}{\delta} \qquad (6.10)$$



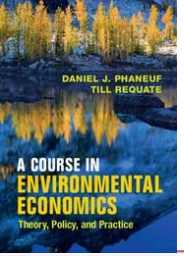
6.1.2 Taxation when abatement is possible

$$\max_{x} \int_0^X P(t)dt - C(X) - D(\delta X) \qquad (6.6)$$

$$\text{FOC: } P(X^*) = C'(X^*) + \delta D'(\delta X^*) \qquad (6.7)$$

- Optimal output X^* and pollution E^* are characterized by:

$$P(X^*) = C_X(X^*, E^*) \qquad (6.13)$$
$$-C_E(X^*, E^*) = D'(E^*).$$



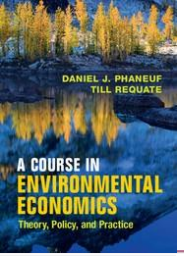
6.1.2 Taxation when abatement is possible

- Regulator‘s problem

$$\max_{\tau} W(\tau) = \int_0^{X^m(\tau)} P(t)dt - C\left(X^m(\tau), E^m(\tau)\right) - D(E^m(\tau)), \qquad (6.14)$$

- Fully differentiating (6.14) with respect to τ leads to FOC:

$$\left[P(X^m) - C_X(X^m, E^m)\right]\frac{dX^m}{d\tau} - \left[C_E(X^m, E^m) + D(E^m)\right]\frac{dE^m}{d\tau} = 0. \qquad (6.15)$$



6.1.2 Taxation when abatement is possible

$$\left[P(X^m) - C_X(X^m, E^m)\right]\frac{dX^m}{d\tau} - \left[C_E(X^m, E^m) + D(E^m)\right]\frac{dE^m}{d\tau} = 0. \qquad (6.15)$$

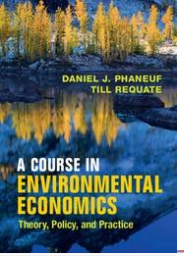
- Substituting the behavioral rules:

$$-C_E(X^m, E^m) = \tau$$

$$-P'(X^m)X^m = P(X^m) + C_X(X^m, E^m)$$

- It yields the second-best tax rate:

$$\tau = D'(E^m) + P'(X^m)X^m \times \frac{dX^m/d\tau}{dE^m/d\tau} < D'(E^m) \qquad (6.16)$$



6.1.2 Taxation when abatement is possible

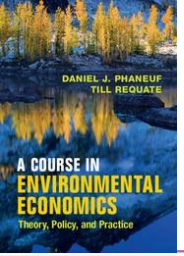
- To establish the signs of $dX^m/d\tau$ and $\frac{dE^m}{d\tau}$, we need to totally differentiate conditions

$$P'(X)X + P(X) = C_X(X,E) \qquad (6.12)$$
$$-C_E(X,E) = \tau.$$

and solve for the two responses, which results in:

$$\frac{dX^m}{d\tau} = \frac{-C_{XE}(\cdot)}{C_{EE}(\cdot)\left[P''(\cdot)X + 2P'(\cdot) - C_{EE}(\cdot)\left\{C_{XX}(\cdot)C_{EE}(\cdot) - C_{XE}^2(\cdot)\right\}\right]} < 0 \qquad (6.17)$$

$$\frac{dE^m}{d\tau} = -\frac{1}{C_{EE}(\cdot)} + \frac{C_{XE}^2(\cdot)}{C_{EE}^2(\cdot)\left[P''(\cdot)X + 2P'(\cdot) - C_{EE}(\cdot)\left\{C_{XX}(\cdot)C_{EE}(\cdot) - C_{XE}^2(\cdot)\right\}\right]} < 0 \qquad (6.18)$$



6.1.2 Taxation when abatement is possible

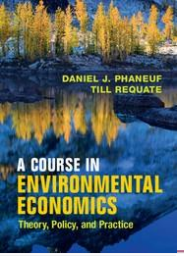
- (6.16) can be rewritten in terms of elasticities:

$$\tau = D'(E^m) - P(X^m)\varepsilon(X^m) \times \frac{dX^m}{dE}, \qquad (6.19)$$

  where $\varepsilon(X^m) = -P'(X^m)X^m/P(X^m)$ is the absolute value of the inverse demand elasticity.
- dX/dE is the change in monopoly output from relaxing the emission constraint.

- If demand elasticity is large (i.e. $\varepsilon(X^m)$ is small), the distortion through imperfect competition is small and the second-best optimal tax is almost at the Pigouvian level.

- If demand is very in-elastic, and therefore $\varepsilon(X^m)$ is large, the regulator has to correct for too little output, and set the emission tax considerably below the Pigouvian level.



6.1.3 Regulating Output and Emissions Simultaneously

- Emission tax τ.
- Subsidy on output ς.

- The firm's profit is given by

$$\Pi(X,E) = \left[P(X) + \zeta\right]X - C(X,E) - \tau E, \qquad (6.20)$$

- F.O.C for profit maximization

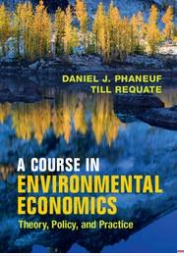
$$P(X) + \zeta + P'(X)X = C_X(X,E)$$
$$-C_E(X,E) = \tau. \qquad (6.21)$$

- If we set $t=D'(E^*)$ and the subsidy so that conditions for profit maximization are now given by

$$\zeta = -P'(X^*)X^*, \qquad (6.22)$$

the first best solution can be obtained.

- Special case of the Tinbergen rule.



Oligopolies

Results are similar: tax lower than marginal damage but higher than under monopoly