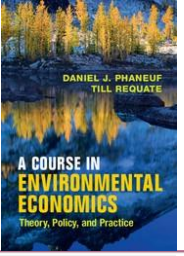


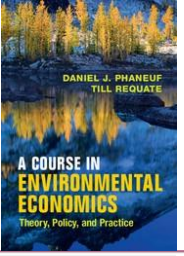
Lecture 3
(Chapter 4 from textbook)

Imperfect Information

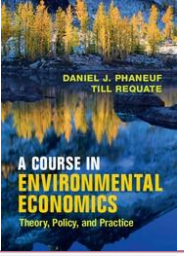


Recapitulation (Ch. 3)

- Defining damage functions and abatement functions.
- Efficient pollution level.
- Menu of policy options.
- Assumption: Consumer preferences and firms' costs are fully known.



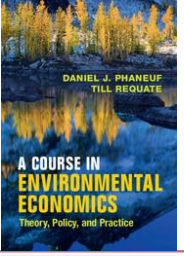
4.1 Price versus Quantities



4.1 Price versus Quantities

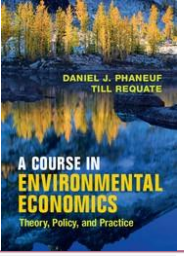
Chapter outline:

- Damage function uncertainty with known abatement cost functions.
- Cost function uncertainty with known damage function.
- Efficiency properties of taxes and permits in these cases.
- Policy implications.



4.1 Price versus Quantities

- **Assumption**: Aggregate and firm level emissions are perfectly observed.
- E = the aggregate pollution level.
- $C(E)$ = the aggregate abatement cost.
- $-C'(E)$ = the aggregate marginal abatement cost (AMAC).
- E^* = optimal level of pollution, satisfying by: $-C'(E^*) = D'(E^*)$.
- Functions estimated with error are denoted with $\sim$:
- $\tilde{D}(\cdot)$ = estimated damage function.
- $\tilde{C}(\cdot)$ = estimated abatement cost function.



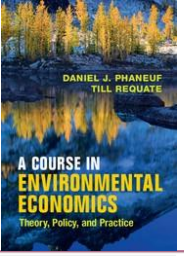
4.1.1 Damage Function Uncertainty

- Suppose regulator underestimates the marginal damage function, i.e.:

$$D'(E) < D'(E) \quad \forall E \tag{4.1}$$

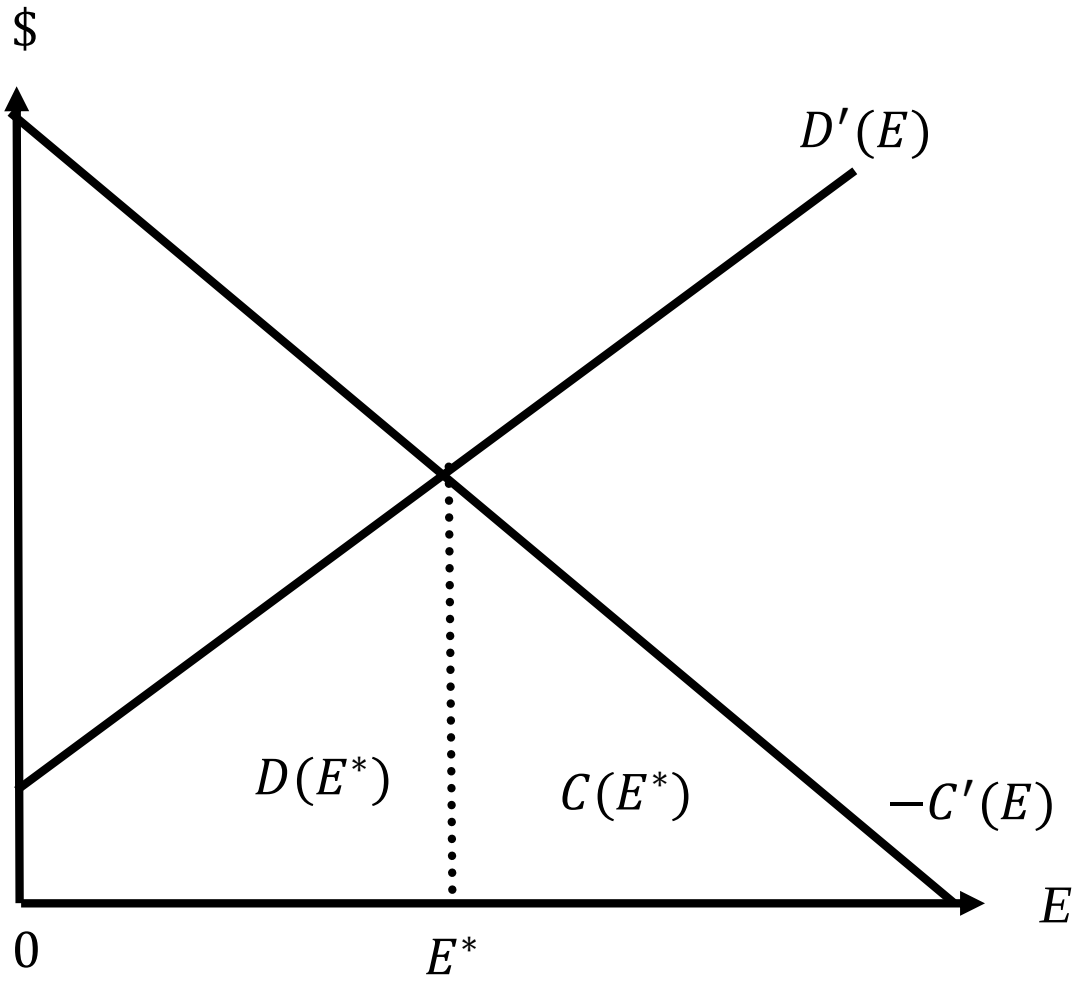
- Then he chooses emissions $\tilde{E}$ according to the rule
- $-C'(E) = \tilde{D}'(E) \quad => \quad \tilde{E} \neq E^*$
- Welfare loss = difference between total social cost realized at $\tilde{E}$ and those that would occur at E^*.

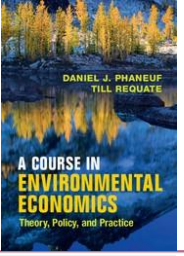
$$WL = \left[D(\tilde{E}) + C(\tilde{E})\right] - \left[D(E^*) + C(E^*)\right] = \int_{E^*}^{\tilde{E}} D'(E)dE - \int_{E^*}^{\tilde{E}} -C'(E)dE \tag{4.2}$$



4.1.1 Damage Function Uncertainty

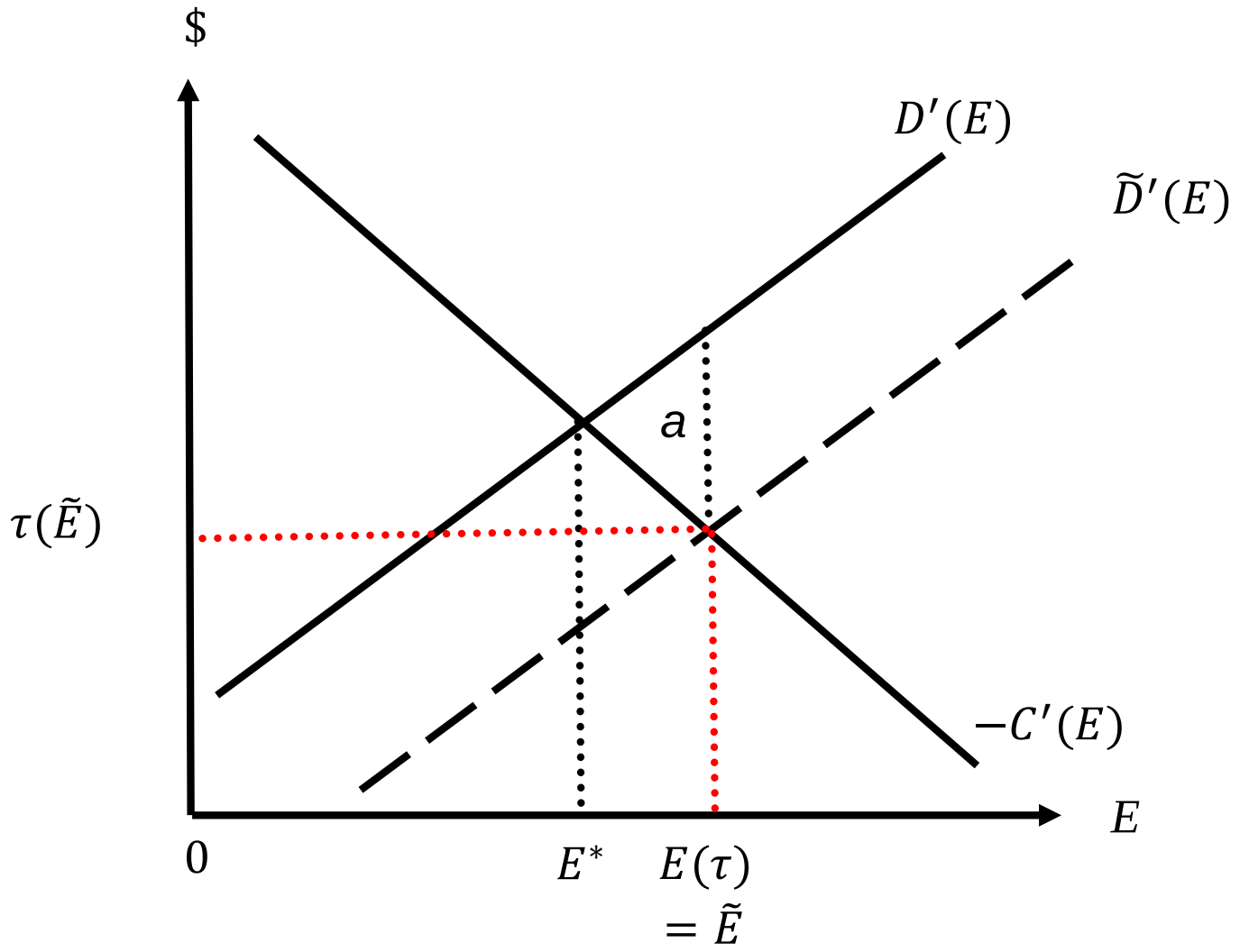
Figure 4.1a Social Cost

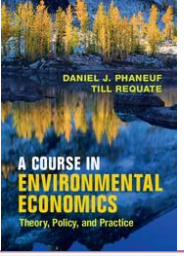




4.1.1 Damage Function Uncertainty

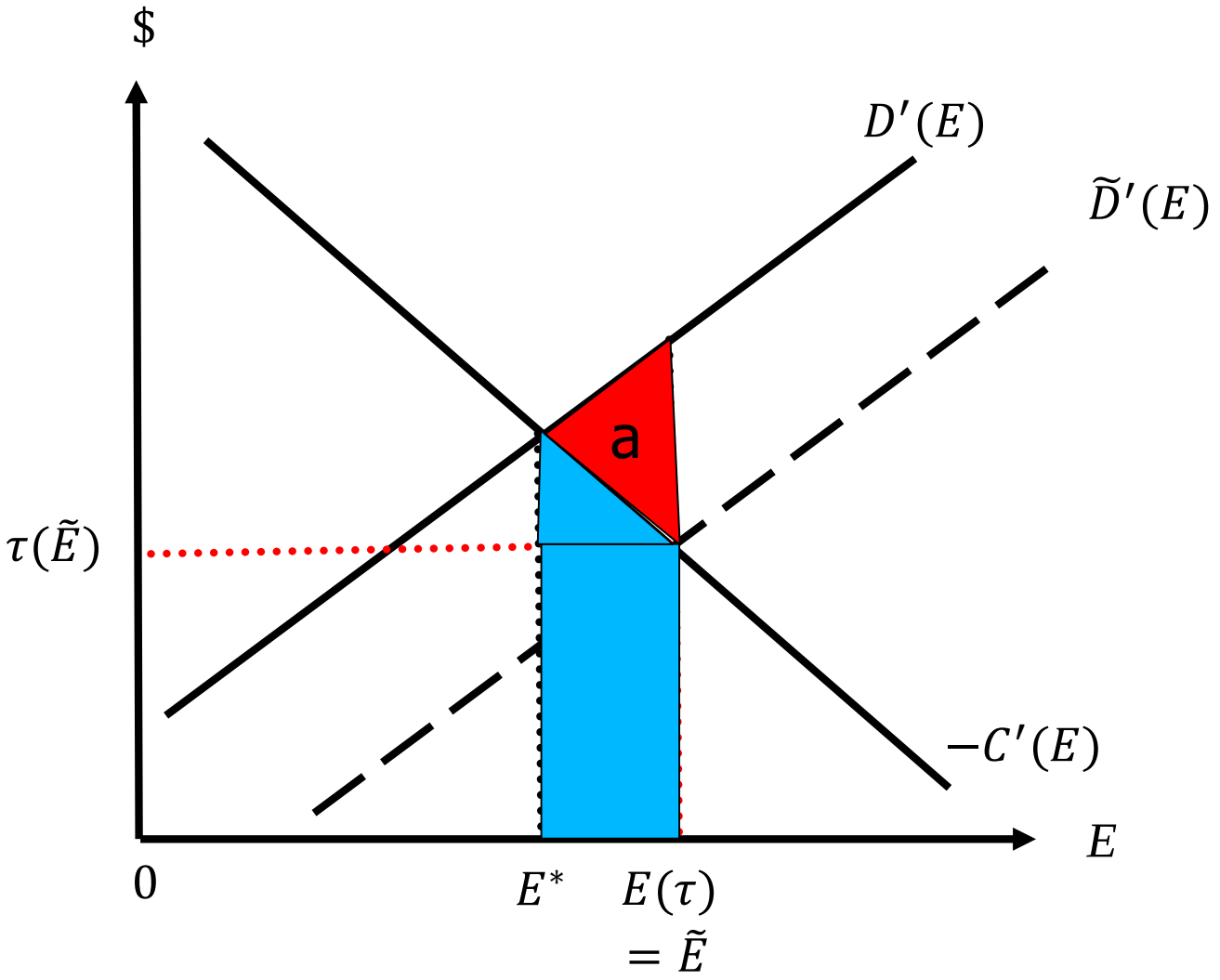
Figure 4.1 Damage cost curve uncertainty

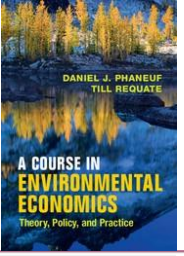




4.1.1 Damage Function Uncertainty

Figure 4.1 Damage cost curve uncertainty





4.1.1 Damage Function Uncertainty

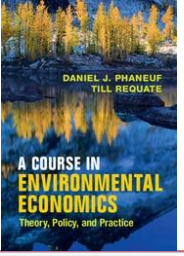
- Last figure shows that the choice of emission tax versus transferable permits results in the same welfare loss (a).

- Blue part: savings in abatement costs,
- Blue + Red part: additional damage
- Red triangle: welfare loss

- With an emission tax regulator sets $\tau(\tilde{E})$.

- With transferable permits regulator distributes or auctions off an amount $L = \tilde{E}$ of permits.

- **Proposition**: Tax (price) and permit (quantity) policy lead to the same welfare loss.

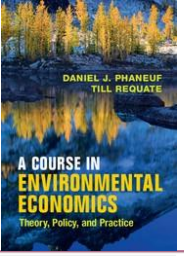


4.1.2 Abatement Cost Function Uncertainty

- Suppose, regulator knows $D(E)$, but needs to estimate $C(E)$.
- Regulator underestimates the true marginal abatement cost curve for all policy relevant emission levels.

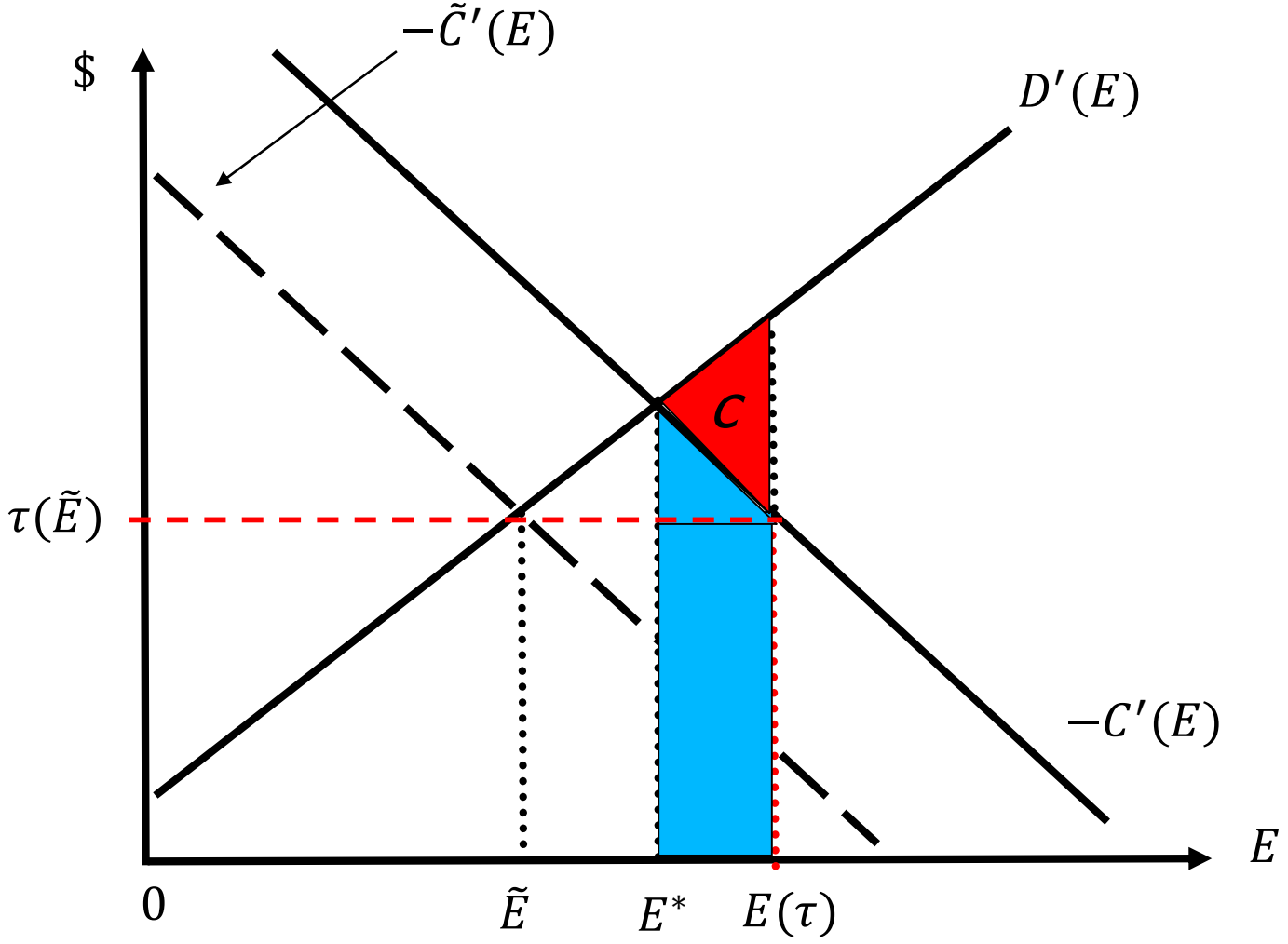
$$-C'(E) < -C'(E) \quad \forall E < \hat{E} \tag{4.3}$$

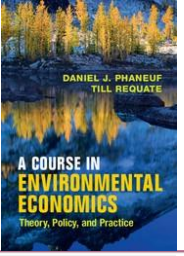
- Emission target $\tilde{E}$ based on: $-\tilde{C}'(E) = D'(E)$
- Difference between tax and permit policies is shown on the next figures.
- Emission tax: $\tau(\tilde{E})$ set such to achieve $\tilde{E}$.
- Permit price $\sigma(\tilde{E})$ emerges at point where permit supply intersects true aggregate marginal abatement cost curve.



4.1.2 Damage Function Uncertainty

Figure 4.1 Abatement cost curve uncertainty, tax policy





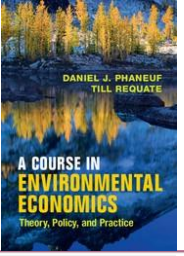
4.1.2 Abatement Cost Function Uncertainty

- Tax policy:

- Blue: abatement cost savings
- Blue + red: additional damage
- Red: Welfare loss:

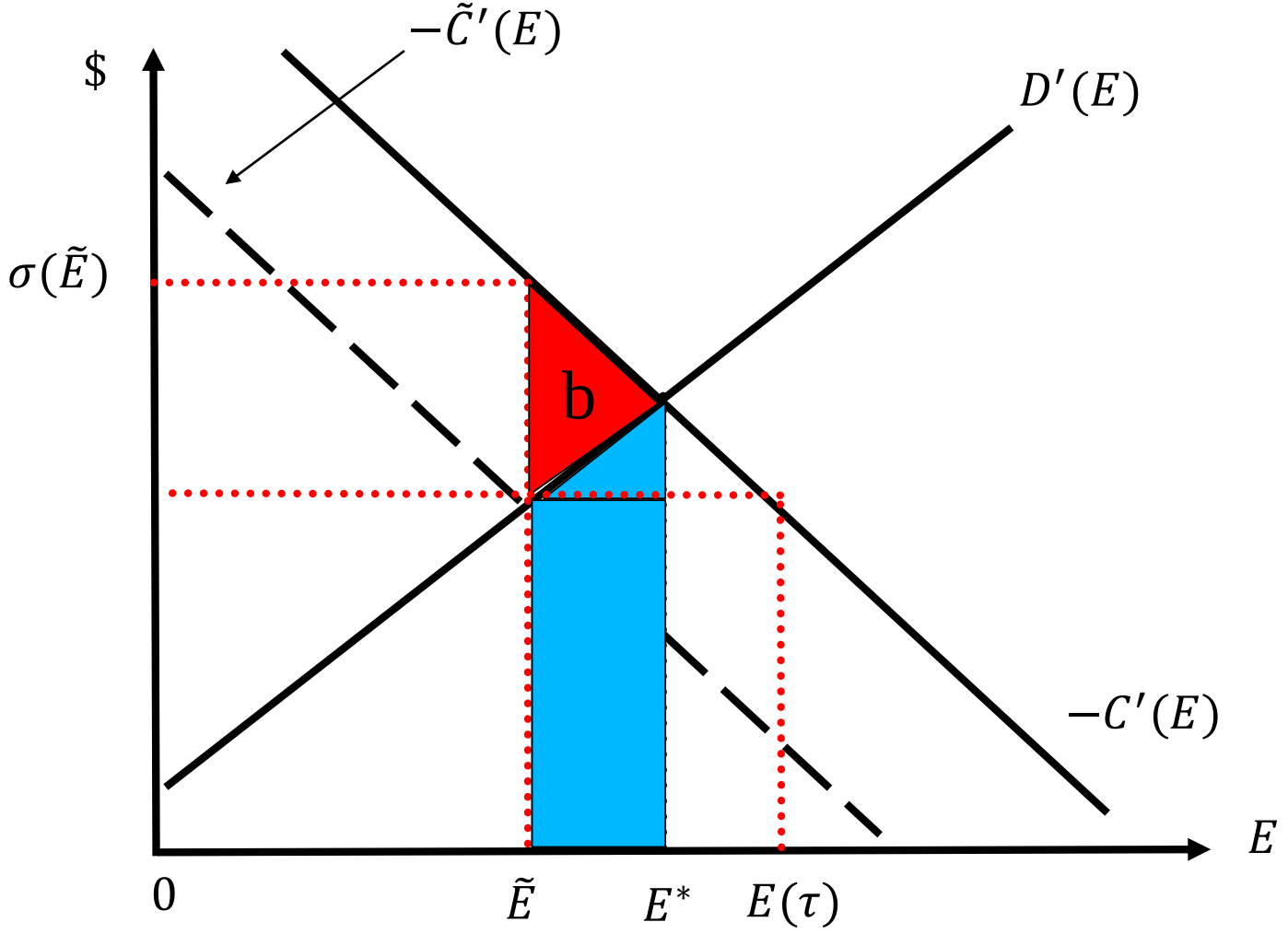
- Welfare loss from tax instrument is area c

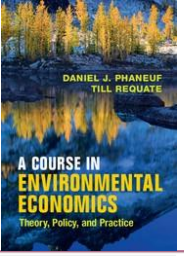
$$c = \int_{E^*}^{E(\tau)} D'(E)dE - \int_{E^*}^{E(\tau)} -C'(E)dE \qquad (4.5)$$



4.1.2 Damage Function Uncertainty

Figure 4.1 Abatement cost curve uncertainty permit policy





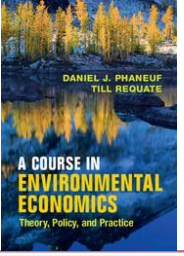
4.1.2 Abatement Cost Function Uncertainty

- Permit policy:

- Blue: additional damage savings
- Blue + red: additional abatement cost
- Red: Welfare loss:

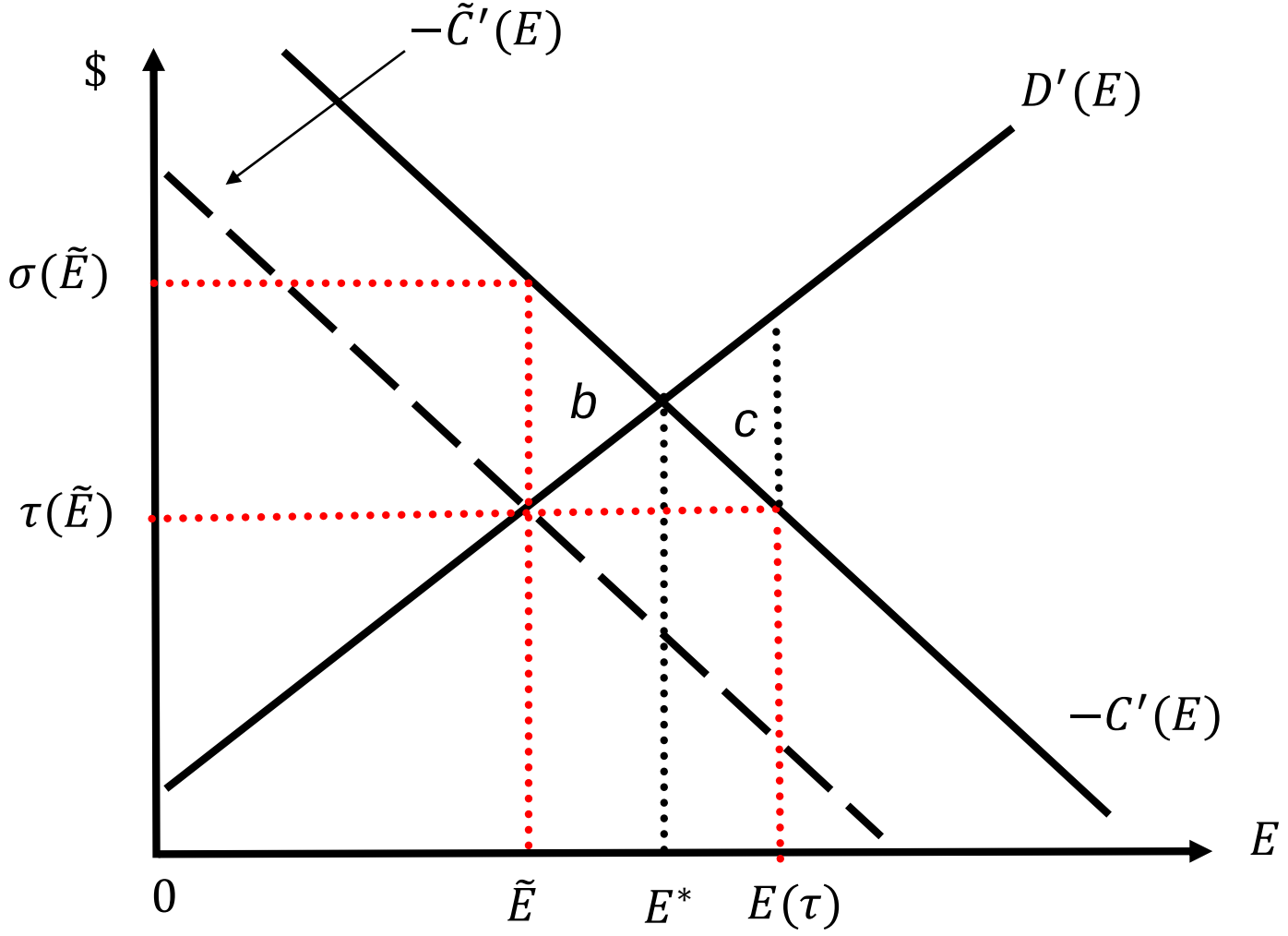
- Welfare loss from permit instrument is area b

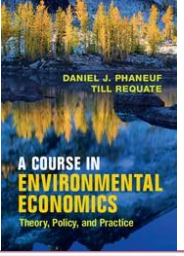
$$b = \int_{\tilde{E}}^{E^*} -C'(E)dE - \int_{\tilde{E}}^{E^*} D'(E)dE \qquad (4.4)$$



4.1.2 Damage Function Uncertainty

Figure 4.1 Abatement cost curve uncertainty, both policies





4.1.2 Abatement Cost Function Uncertainty

- Welfare loss from the quantity instrument is area b

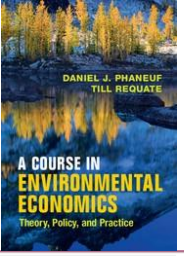
$$b = \int_{\tilde{E}}^{E^*} -C'(E)dE - \int_{\tilde{E}}^{E^*} D'(E)dE \qquad (4.4)$$

- Under the quantity instrument, regulator supplies $L = \tilde{E}$.

- Welfare loss from tax instrument is area c

$$c = \int_{E^*}^{E(\tau)} D'(E)dE - \int_{E^*}^{E(\tau)} -C'(E)dE \qquad (4.5)$$

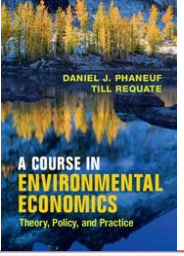
- Inspection of figure and analytical expressions suggest we cannot make general statement about relative size of the respective welfare losses.



4.1.2 Abatement Cost Function Uncertainty

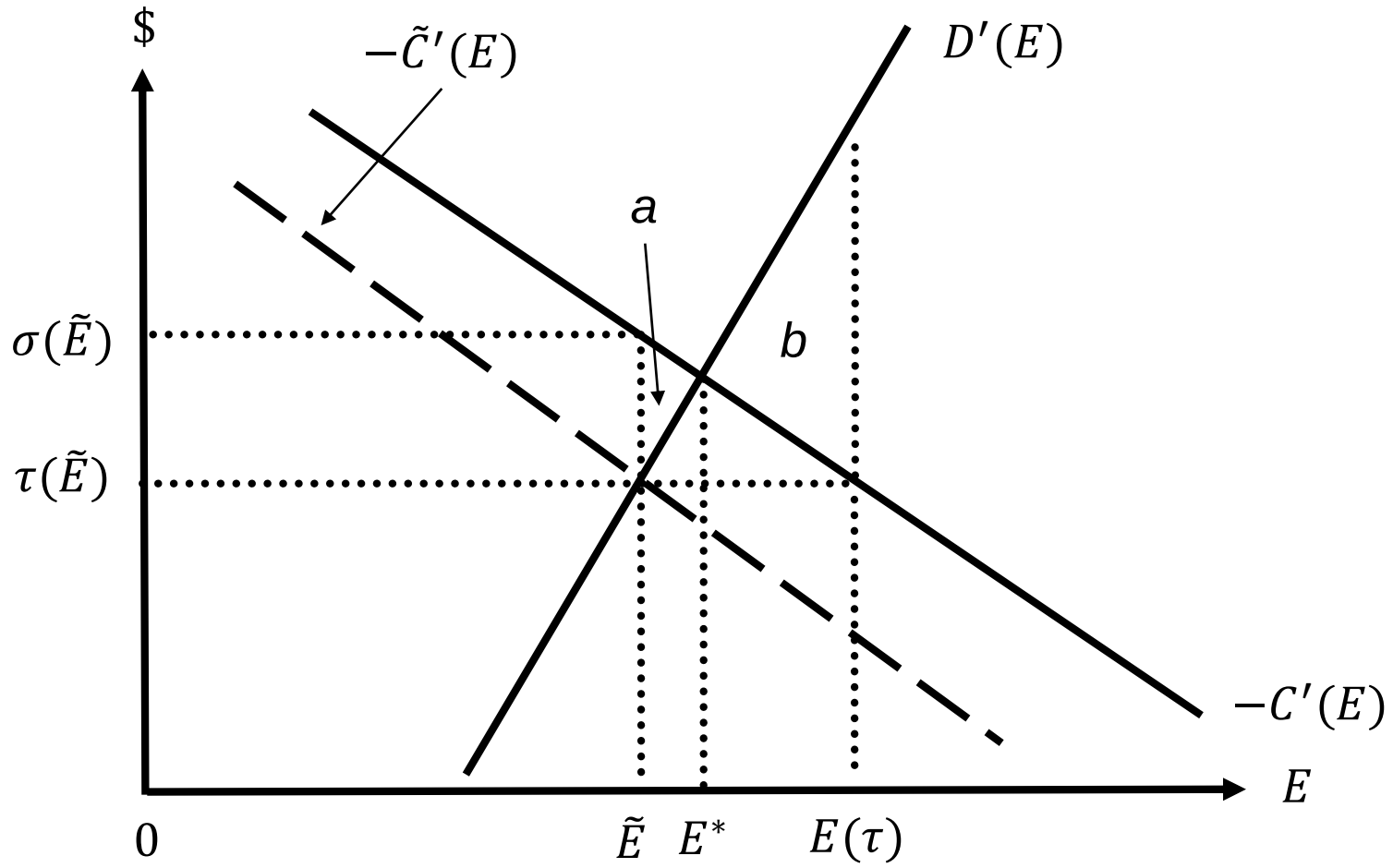
- The next two figures show welfare losses for different slopes of marginal damage curves intersecting $-\tilde{C}'(\cdot)$ at $\tilde{E}$.

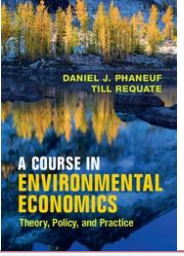
- In both cases the regulator
  allocates $L = \tilde{E}$ to implement a quantity instrument
  or sets $\tau = \tau(\tilde{E})$ to implement a price instrument.



4.1.2 Abatement Cost Function Uncertainty

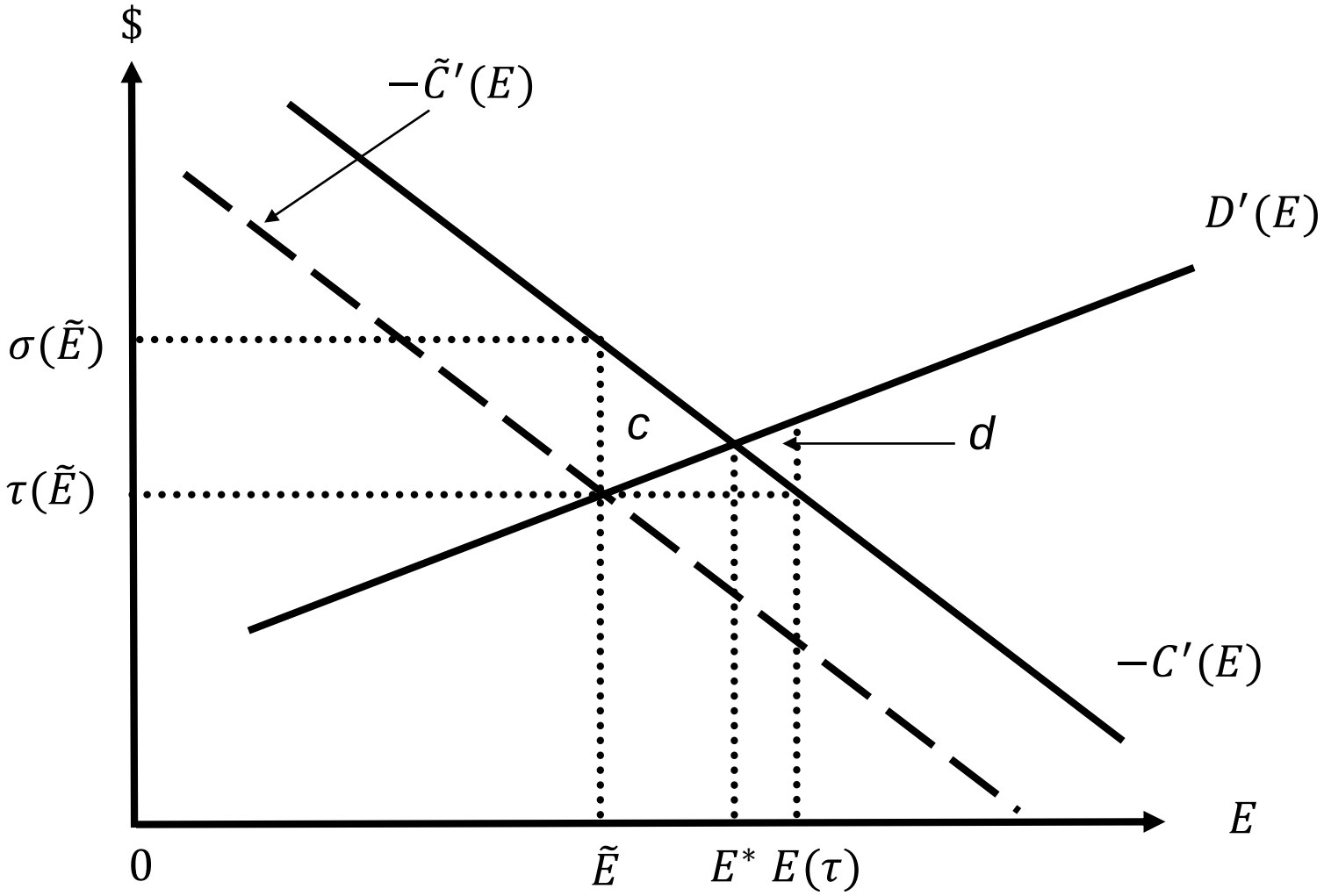
Figure 4.2 Panel A: Welfare loss with steep damage cost curve.

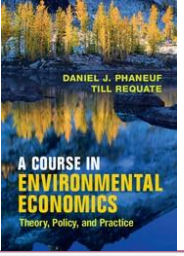




4.1.2 Abatement Cost Function Uncertainty

Figure 4.2 Panel B: Welfare loss with flat damage cost curve.





4.1.2 Abatement Cost Function Uncertainty

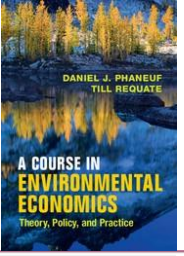
- In panel A the tax instrument leads to a higher welfare loss $(b > a)$ due to the larger resulting distance between the optimal and the realized emission level.

- In panel B with flat marginal damage curve, $c > d$, and a tax policy leads to a smaller welfare loss.

- This intuition can be made more formal by writing the marginal damage function to include an explicit parameter η for its slope.

- $D(E, \eta)$ and assuming $D_{E\eta}(\cdot) > 0$

- Note: optimal pollution level E^* depends on η.



Proposition 4.1

- *Suppose the regulator has an estimate* $-\tilde{C}(E)$ *of the true aggregate marginal abatement cost curve* $-C(E)$ *such that:*

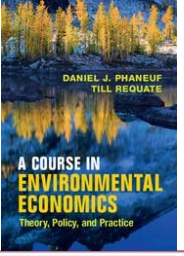
$$-\tilde{C}'(E) \neq -C'(E)$$

- *Consider pollution level* $\tilde{E}$ *defined by* $-\tilde{C}'(\tilde{E}) = D_E(\tilde{E}, \eta)$.

Then: for larger values of η *, i.e. a steeper marginal damage curve.*

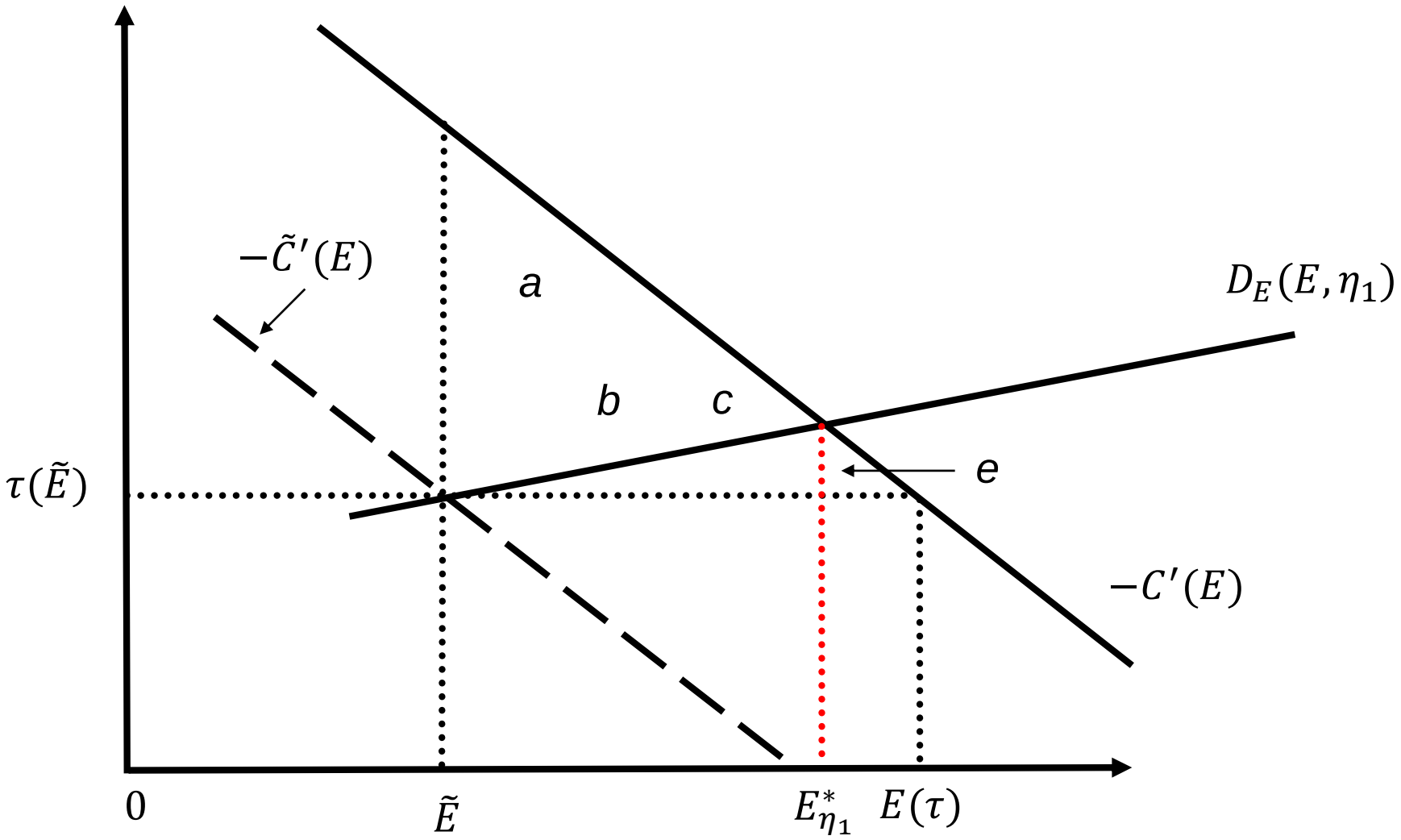
a. *The gap* $|E^*(\eta) - \tilde{E}|$ *becomes smaller and the welfare loss under a permit policy shrinks*.

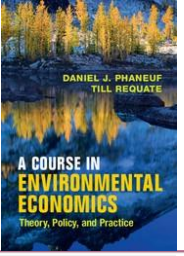
b. *The gap* $|E^*(\eta) - E(\tau)|$ *becomes larger and the welfare loss under a tax policy increases, where* $E(\tau)$ *is the emission level that occurs under the tax* $\tau = \tau(\tilde{E})$.



Proposition 4.1

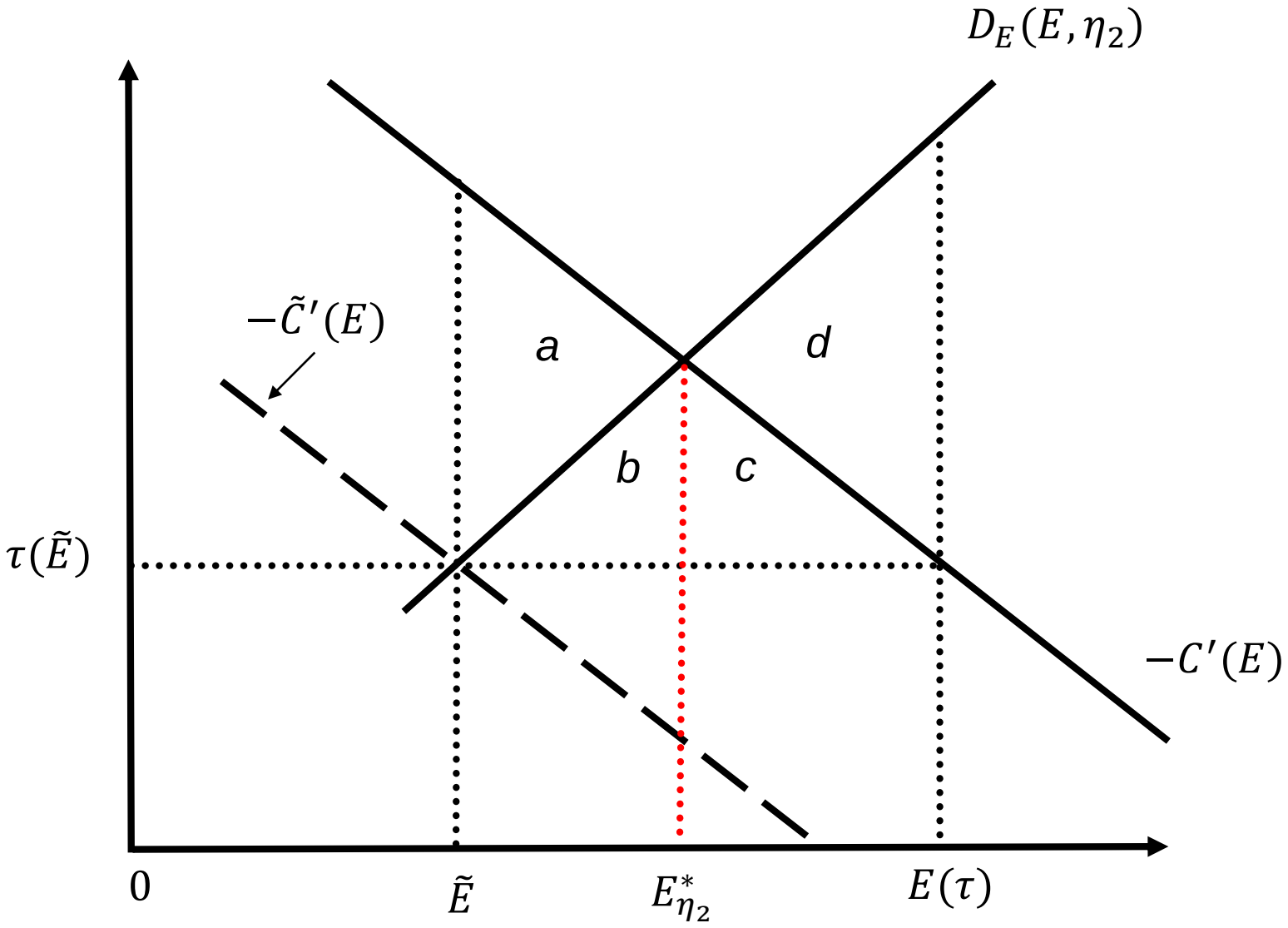
Figure 4.3 Illustration of Proposition 4.1

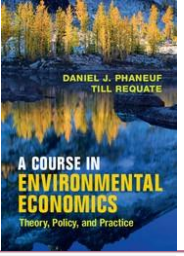




Proposition 4.1

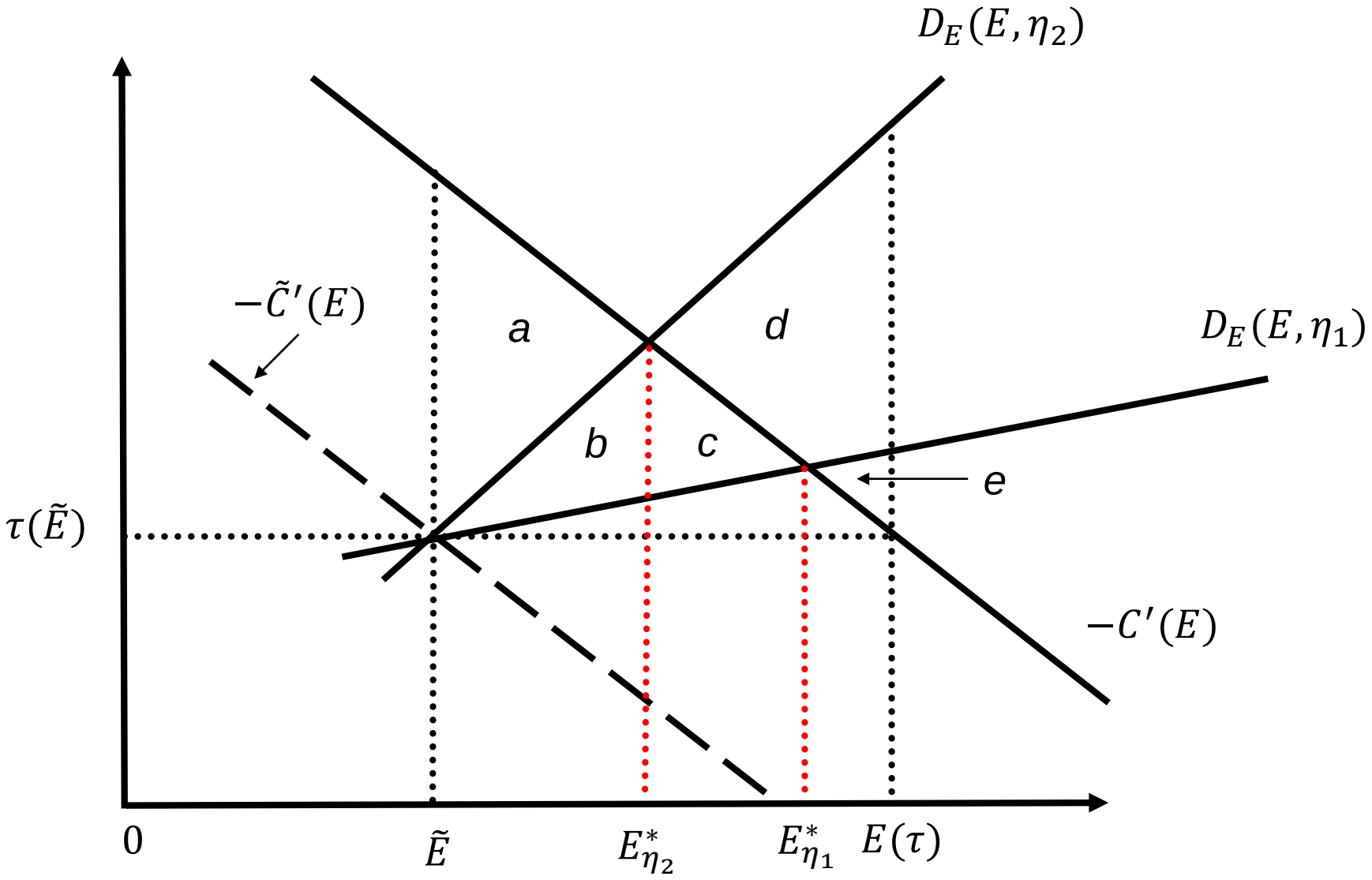
Figure 4.3 Illustration of Proposition 4.1

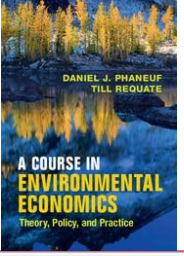




Proposition 4.1

Figure 4.3 Illustration of Proposition 4.1



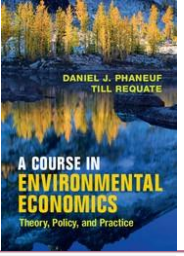


4.1.3 The Weitzman Theorem

For linear marginal damage and marginal abatement cost curves Martin Weitzman (1974) proved that

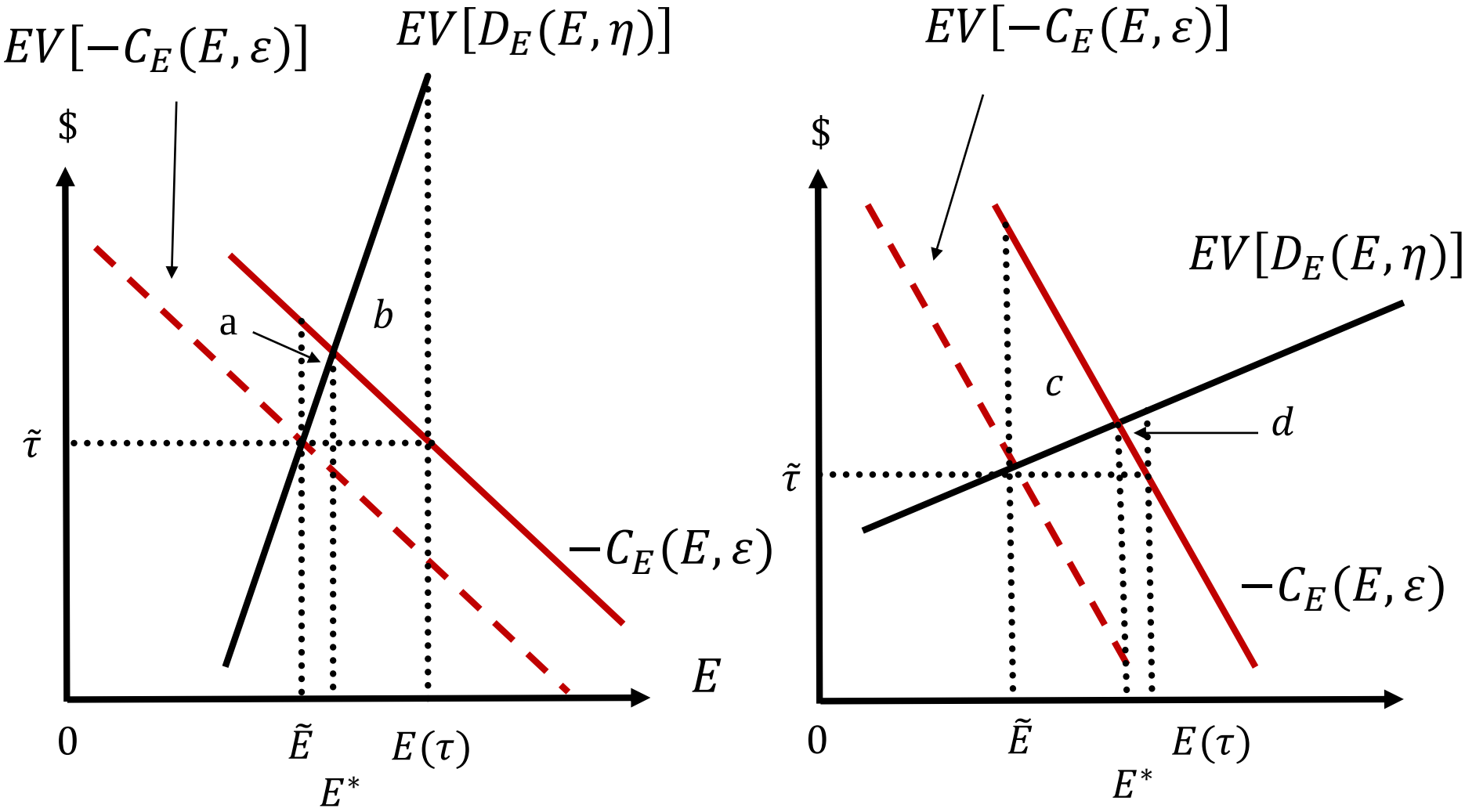
- the welfare loss under a tax policy is larger than the welfare loss under a permit policy **if and only if** the absolute slope of the marginal damage function is larger than the absolute slope of the marginal abatement cost curve.

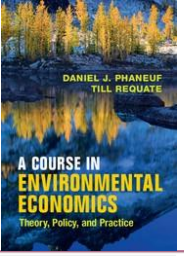
This Weitzman paper is one of the most influential and most cited papers in environmental economics!



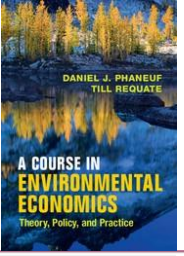
The Weitzman Theorem

Figure 4.4: Illustration of the Weitzman Theorem





4.2 Hybrid Policies



4.2.1 Non-Linear Tax

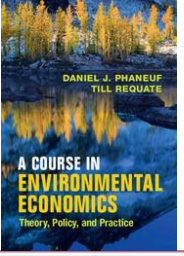
- Consider again the case of a known damage function $D(E)$ but unknown abatement cost function.
- Define a pollution tax schedule $\tau(E)$ based on total emissions such that $\tau(E) = D'(E)$.
- Assumption: firms cannot influence the tax schedule, i.e. firms take tax rate as given.
- Firm j´s pollution-related total cost under this type of policy is:

$$TC_j = C_j(e_j) + \tau(E) \cdot e_j \qquad (4.19)$$

F.o.c. for cost minimization:

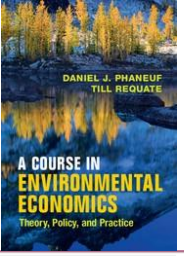
$$-C_j'(e_j) = \tau(E) = D'(E)$$

yielding a first-best allocation.



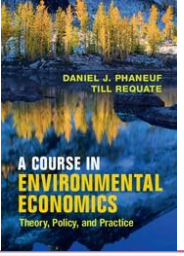
4.2.1 Non-Linear Tax

- A problem is that the tax needs to react relatively quickly to changes in emissions.
- But in fact such fees are sometimes applied in congestion highway fees. More congestion: higher fees



4.2.2 Safety Valves

- Roberts and Spence (1976) suggest a mixed system consisting of
  - Emission permits
  - Emission taxes
  - Abatement subsidies
- Polluting industry receives
  - an allocation of **transferable permits**
  - option to pay an **emission tax** on additional emissions not covered by permits
  - option to sell non-used permits to the government at a guaranteed price.
- By providing such safety valves, the government protects industry against too high costs and protects the environment against too low abatement efforts.



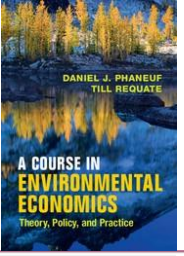
4.2.2 Safety Valves

Formally:

- The regulator allocates or auctions off an amount $L = \tilde{E}$ of permits based on the known damage function.

- σ = permit price.
- $\overline{e}_j$ = permit quantity held by firm j after permit market clears.

- Additionally, the regulator:
  - charges a tax if the firm‘s emissions exceed $\overline{e}_j$,
  - pays a subsidy if the firm‘s emissions fall short of $\overline{e}_j$.



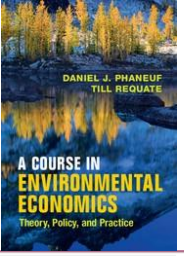
4.2.2 Safety Valves

Firm's objective function:

$$\min_{e_j,\bar{e}_j} TC_j = \begin{cases} C_j\left(e_j\right)+\sigma\cdot\bar{e}_j+\tau\cdot\left(e_j-\bar{e}_j\right) & e_j \geq \bar{e}_j \\ C_j\left(e_j\right)+\sigma\cdot\bar{e}_j-\varsigma\cdot\left(\bar{e}_j-e_j\right) & e_j \leq \bar{e}_j \end{cases} \tag{4.20}$$

- **Proposition**: The permit price is bounded by the tax and the permit rate:

$$\varsigma \leq \sigma \leq \tau$$



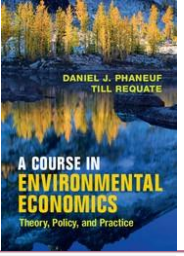
4.2.2 Safety Valves

Proof:

- If $\sigma > \tau$, firms will choose to pay the emission tax rather than covering emissions with more expensive permits. Firms will sell their permits and the permit price will fall at least until $\sigma \leq \tau$.

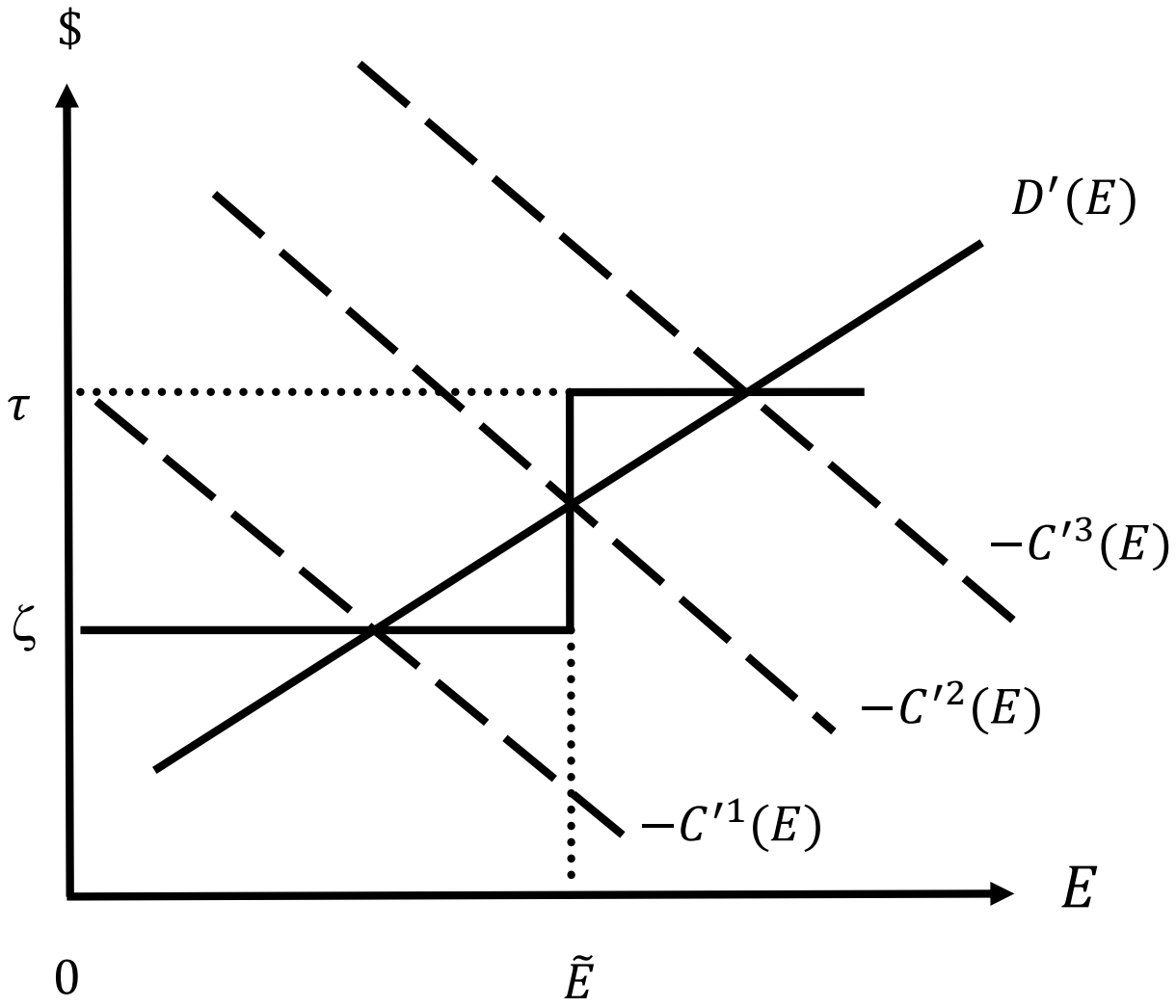
- If $\sigma < \varsigma$ firms could earn a profit by buying permits at σ and turning them back for the larger amount ς. This type of arbitrage opportunity will increase the demand for permits, and push the price up at least until $\varsigma \leq \sigma$. So in equilibrium, it must be the case that $\varsigma \leq \sigma \leq \tau$.

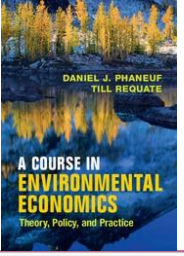
- If $\varsigma < \sigma < \tau$, firms set $e_j = \bar{e}_j$, and it is cheaper to cover emissions with a permit than to pay the tax. In this case firms choose emissions such that: $-C_j'(e_j) = \sigma$.



4.2.2 Safety Valves

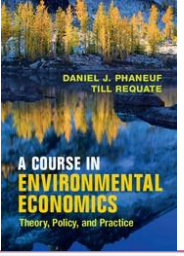
Figure 4.5 Panel A: Roberts and Spence Instrument





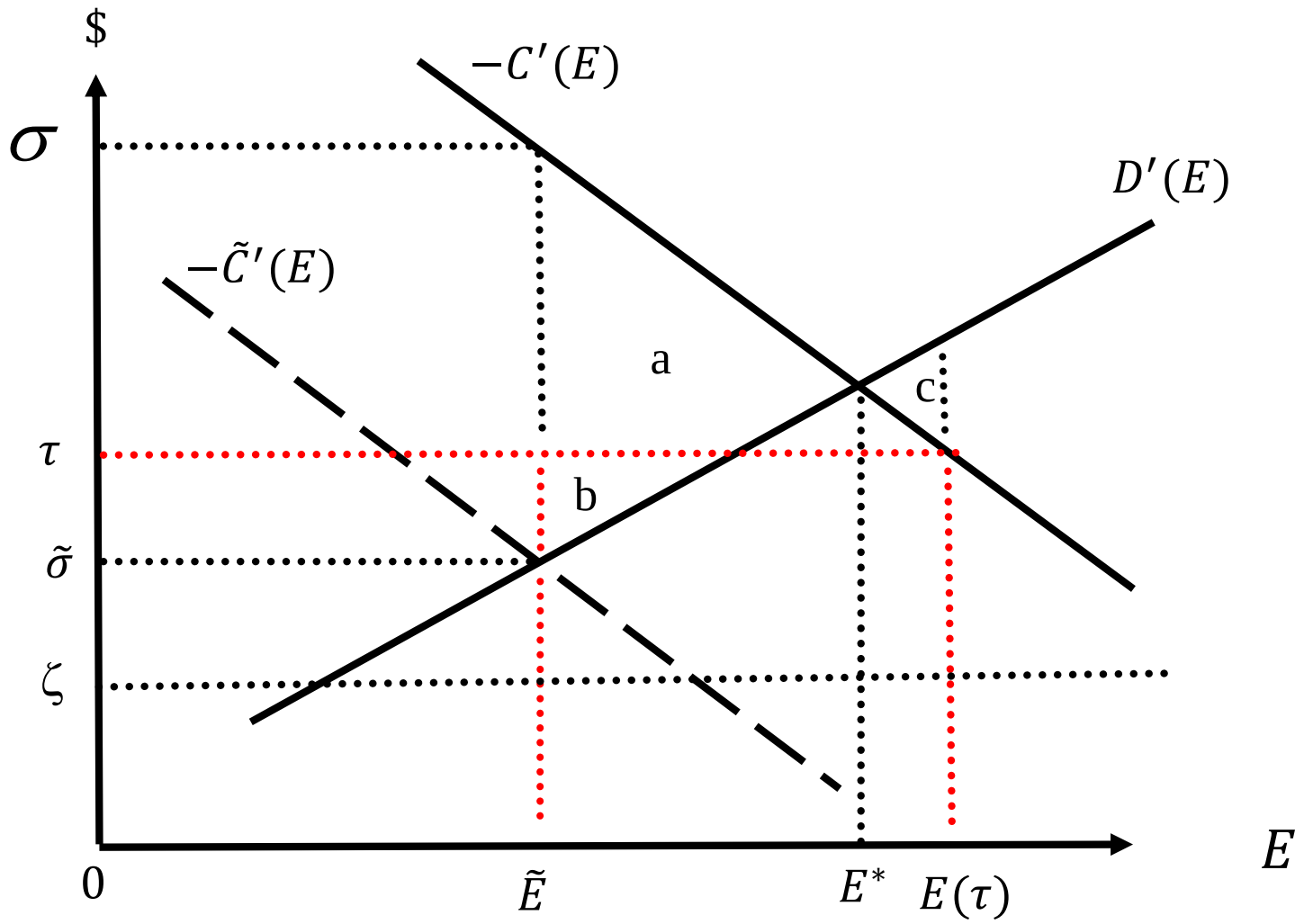
4.2.2 Safety Valves

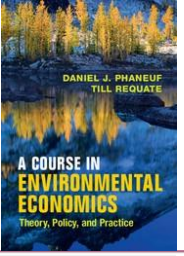
- Panel A shows three different aggregate marginal abatement cost curves and policy parameters corresponding to $L = \tilde{E}, \tau, \varsigma$.
- By specifying the prices along with the quantity the regulator can achieve an efficient outcome (zero welfare loss) for three possible marginal abatement cost curves:
- For the cost function $C^1(E)$, the relevant policy parameter is ς, and firms receives subsidies for reducing emissions below $\tilde{E}$.
- For $C^2(E)$ the market policy of permits lies between τ and ς, suggesting the quantity parameter $L = \tilde{E}$ is in play.
- For $C^3(E)$ the tax level determines aggregate emissions in that firms pay τ for each unit of pollution beyond $\tilde{E}$.



4.2.2 Safety Valves

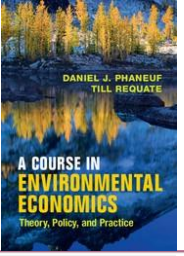
Figure 4.5 Panel B: Roberts and Spence Instrument





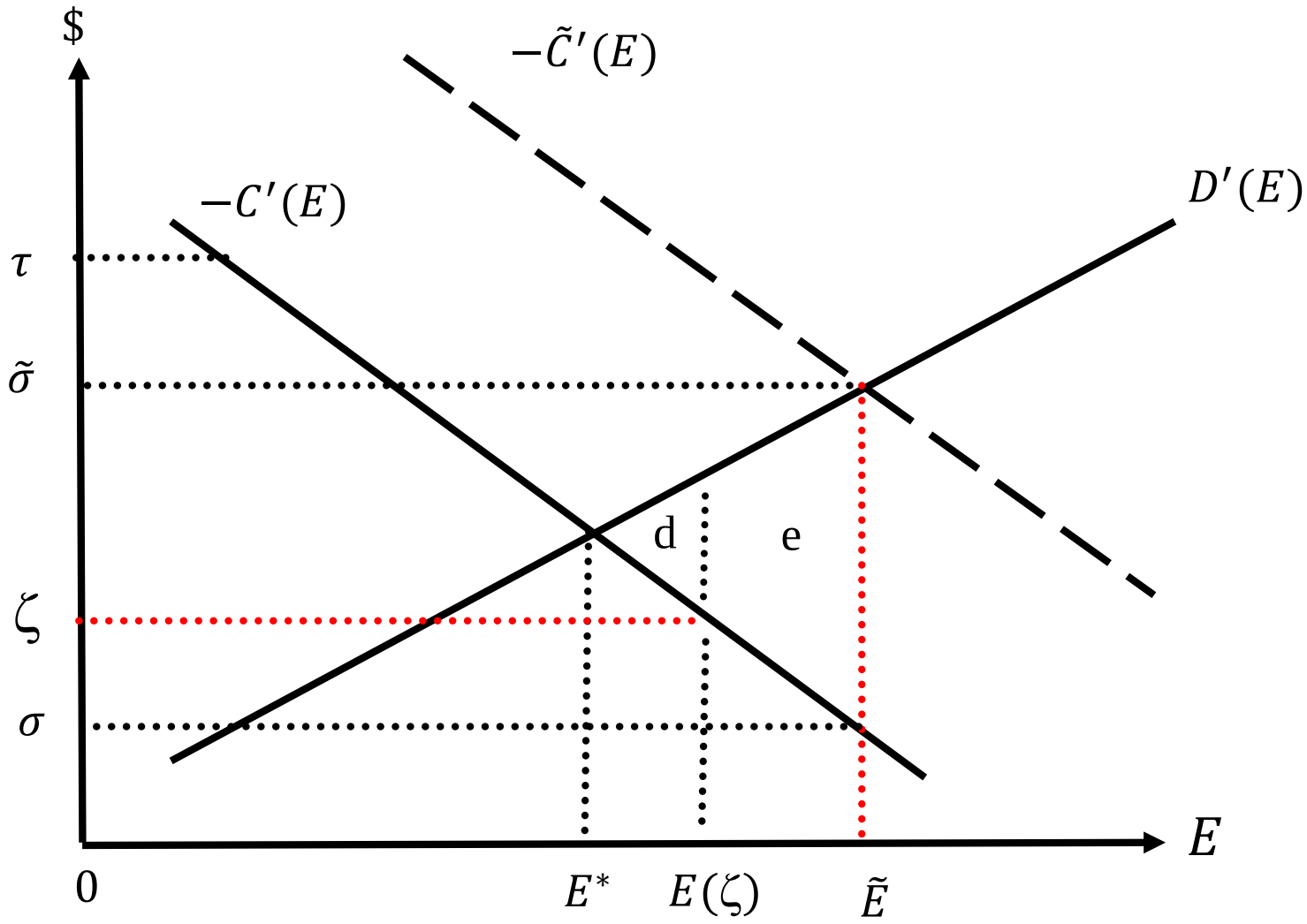
4.2.2 Safety Valves

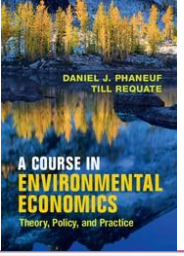
- Panel B shows a situation where the regulator estimates marginal abatement cost curve $-\tilde{C}'(E)$, but the true curve is $-C'(E)$.
- Under a pure permit market, the resulting true permit price would be σ , and the welfare loss would result in a+b,
- Under the safety valve with an additional tax rate τ the welfare loss is just c.



4.2.2 Safety Valves

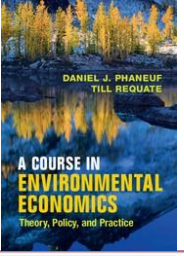
Figure 4.5 Panel C: Roberts and Spence Instrument





4.2.2 Safety Valves

- Panel C shows a situation where the regulator estimates marginal abatement cost curve $-\tilde{C}'(E)$, but the true curve is $-C'(E)$
- Under a pure permit market, the resulting true permit price would be $\bar{\sigma}$, and the welfare loss would result in e+d,
- Under the safety valve with an additional subsidy rate ζ the welfare loss is just d.



4.2.2 Safety Valves

Summary

- A hybrid policy of this type provides advantages over pure price or quantity instruments when the regulator is uncertain about abatement costs.
- If the regulator underestimates the aggregate marginal abatement cost curve (and therefore the price of permits), the tax rate serves to cap the firms' marginal abatement cost levels.
- If the regulator overestimates the aggregate marginal abatement cost (and therefore the price of permits), the subsidy assures there are still incentives for emissions reductions.