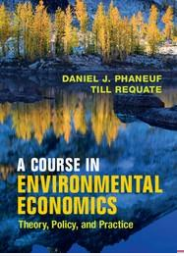


Environmental Economics

Lecture 5

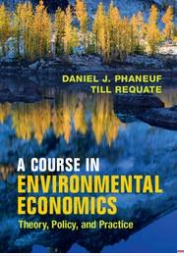
(based on Chapter 12 textbook)

International Environmental Problems

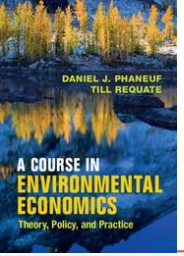


Issues

- In the international dimension of environmental economics there are several issues to be addressed:
- Transboundary pollution: emissions from one country affect other countries
- Environmental Policy affects the terms of trade.
- By this environmental policy can be abused as trade policy.
- We will study the effects of domestic environmental policy under both perfect and imperfect competition.
- We will also study whether trade liberalization per se increases pollution.

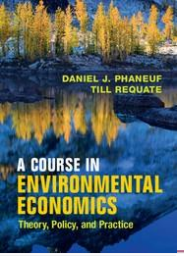


12.1 Transboundary Pollution in an Autarky Model



12.1.1 Model

- There are two countries, home and foreign.
- Each country produces only one good emitting a pollutant.
- Initially, the two goods cannot be traded and may physically of different kind (apples in one country, oranges in another country).
- The pollutant is transboundary and thus affects the respective other country.
- Abatement costs are measured in lost (foregone) output.
- Since output is different, abatement costs are non-comparable!
- Still, there may be benefits from cooperation between countries.

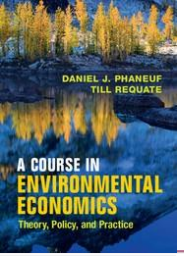


12.1.1 Model

- $C(E)$ and $C_f(E_f)$ denote the home and foreign country's abatement cost of moving to an emissions level $E < \hat{E}$.
- Costs are measured in terms of forgone production.
- Consumer utility functions are $U(z, E, E_f)$ and $U_f(z_f, E; E_f)$ for the home and foreign countries.
- $z = y - C(E)$ and $z_f = y_f - C_f(E_f)$ are the consumption levels.
- By substituting out for consumption, the utility functions can be expressed as a function of emissions only:

$$u = U(y - C(E), E, E_f) \qquad (12.1)$$
$$u_f = U^f(y_f - C(E_f), E, E_f)$$

- $U_z > 0, U_E < 0$, and $U_{E_f} < 0$



12.1.1 Model

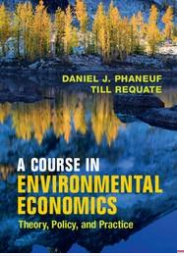
- For the case of a **homogeneous** global pollutant for which the location of emissions does not matter, it yields

$$u = U\left(y - C(E), E + E_f\right) \tag{12.2}$$
$$u_f = U^f\left(y_f - C(E_f), E + E_f\right)$$

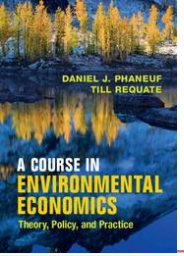
- If the pollutant is non-uniform mixing, such that one country is only partially affected by the other's emissions, it follows

$$u = U\left(y - C(E), \alpha E + \beta E_f\right) \tag{12.3}$$
$$u_f = U^f\left(y_f - C(E_f), \alpha_f E + \beta_f E_f\right)$$

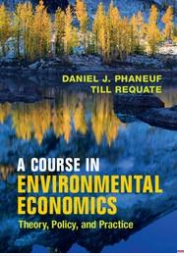
where (α, β) and (α_f, β_f) are transmission coefficients indicating how much domestic emissions and emissions from abroad affect domestic utility, for both countries.


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One day



The other day



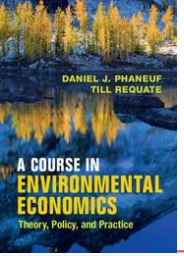
12.1.2 Non-cooperative Behavior

- The two countries play a non-cooperative game whereby the players solve the following problems:

$$\max_E \{U(y - C(E), E, E_f)\} \qquad (12.4)$$
$$\max_{E_f} \{U^f(y_f - C_f(E_f), E, E_f)\}$$

- The Nash equilibrium of this game is determined by the F.O.C's

$$-C'(E) \cdot U_z(z, E, E_f) + U_E(z, E, E_f) = 0 \qquad (12.5)$$
$$-C_f'(E_f) \cdot U_{z_f}^f(z_f, E, E_f) + U_{E_f}^f(z_f, E, E_f) = 0$$



12.1.2 Non-cooperative Behavior

- Upon rearranging, we obtain

$$-C'(E) = -\frac{U_E(z,E,E_f)}{U_z(z,E,E_f)} \tag{12.6}$$

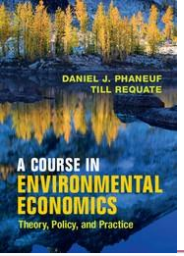
and

$$-C'_{E_f}(E_f) = -\frac{U^f_{E_f}(z_f,E,E_f)}{U^f_{z_f}(z_f,E,E_f)} \tag{12.7}$$

- i.e. the marginal abatement cost equals the MRS between the consumption good an pollution.

- Denote the resulting non-cooperative emission levels by (E^N, E_F^N) and the non-cooperative utility levels by

$$u^N = U\left(y^N - C(E^N), E^N, E_f^N\right) \tag{12.8}$$
$$u_f^N = U^f\left(y_f^N - C(E_f^N), E^N, E_f^N\right)$$



12.1.3 Cooperative Behavior

- Assuming an interior solution for emissions in both countries, the maximization problem is given by

$$\max_{E,E_f} L = U\left(y - C(E), E, E_f\right) + \lambda\left[U^f\left(y_f - C_f(E_f), E, E_f\right) - \bar{u}_f\right] \tag{12.9}$$

F.O.C's are

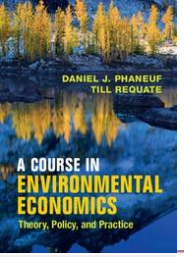
$$-C'(E)\cdot U_z + U_E + \lambda U_E^f = 0 \tag{12.10}$$
$$-\lambda C_f'(E_f)\cdot U_{z_f}^f + \lambda U_{E_f}^f + U_{E_f} = 0$$

- Rearranging the top condition for the home country yields

$$-C'(E) = \frac{-\left(U_E + \lambda U_E^f\right)}{U_z} \tag{12.11}$$

- Equivalently, rearranging the bottom condition leads to

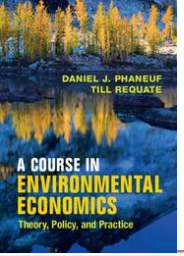
$$-C_f'(E_f) = \frac{-\left(U_{E_f} + \lambda U_{E_f}^f\right)}{\lambda U_{z_f}^f} \tag{12.12}$$



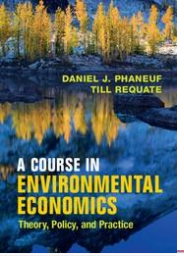
12.1.3 Cooperative Behavior

- These conditions point out, that in a cooperative solution, each country sets emissions based on the weighted sum of the marginal disutility in both countries.

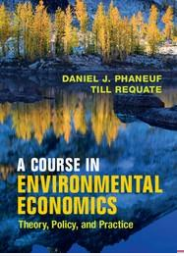
- It is important to note that it is not possible to directly compare the marginal abatement costs across two countries, since abatement costs are measured in units of the production good for the respective countries, which need not be the same in both places.



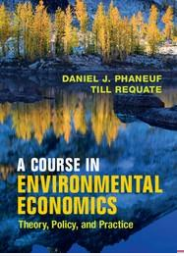
Third day: negotations


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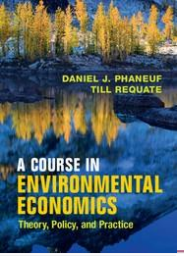
Result



Alternative result



Another alternative

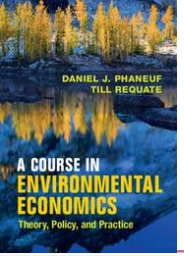


12.1.3 Cooperative Behavior

Limits to Cooperation

- If the two countries are not able to transfer commodities, but nevertheless can communicate, a cooperative outcome that obeys the efficiency conditions (12.11) and (12.12) is possible.
- The cooperative outcome must satisfy participation (or individual rationality) constraints.
- Define (E^C, E_F^C) as the solution to (12.11) and (12.12), and let the resulting utility levels be given by

$$u^C = U\left(y^C - C(E^C), E^C, E_f^C\right)$$
$$u_f^C = U^f\left(y_f^C - C(E_f^C), E^C, E_f^C\right) \qquad (12.13)$$

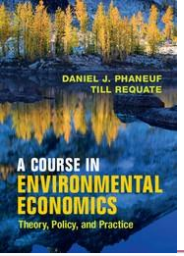


12.1.3 Cooperative Behavior

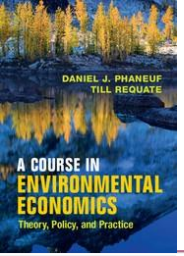
- The participation constraints then require that

$$u^C \geq u^N \qquad (12.14)$$
$$u_f^C \geq u_f^N$$

- This means that utility for the representative individual in both countries should be higher under cooperation than under non-cooperation, if the former is feasible.

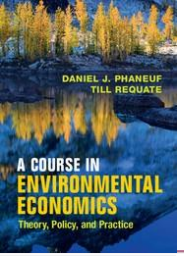


12.2 Commodity Transfer

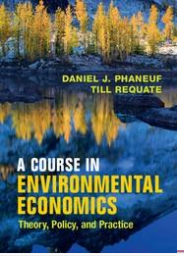


12.1.3 Cooperative Behavior

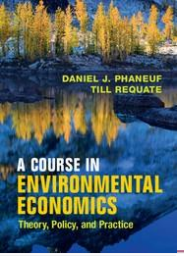
- Assume that one country is more heavily affected by the pollution of the other country as compared to vice versa.
- Say, the wind mostly blows pollutants from country A to country B.
- If there is no way of commodity transfer there is no way for a win-win situation. Just bad luck for country B.
- If, however, commodities can be transferred (even if the good is homogenous), there is potential for a win-win situation:
- Country B delivers **goods** to country A **in exchange** for **emission reductions** by country A.



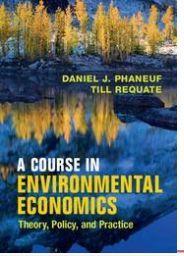
Country B (right hand side) is more affected by pollution than country A (left hand side)



Again: negotations



Result: Goods for emission reductions



12.2 Commodity Transfer

- To find a Pareto optimal allocation with possible commodity transfer between the countries we solve

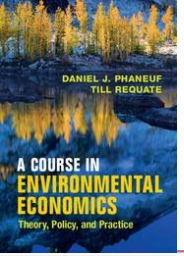
$$\max_{z,z_f,E,E_f} L = U(z,E,E_f) \quad s.t. \quad U^f(z_f,E,E_f) \geq \bar{u}_f \tag{12.15}$$

s.t. the feasibility constraint

$$z + z_f = y + y_f - C(E) - C_f(E_f) \tag{12.16}$$

- The Lagrangian for the Pareto problem now reads

$$\max_{z,z_f E,E_f} L = U(z,E,E_f) + \lambda\left[U^f(z,E,E_f) - \bar{u}_f\right] \tag{12.17}$$
$$- \mu\left[z + z_f - y - y_f + C(E) + C_f(E_f)\right]$$



12.2 Commodity Transfer

$$\max_{z,z_f E,E_f} L = U(z,E,E_f) + \lambda\left[U^f(z_f,E,E_f) - \bar{u}_f\right] \qquad (12.17)$$
$$- \mu\left[z + z_f - y - y_f + C(E) + C_f(E_f)\right]$$

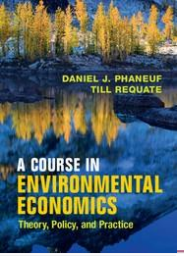
- F.O.C's of (12.17) are

$$\frac{\partial L}{\partial z} = U_z - \mu = 0 \qquad (12.18)$$
$$\frac{\partial L}{\partial z_f} = \lambda U^f_{z_f} - \mu = 0$$

and

$$\frac{\partial L}{\partial E} = U_E + \lambda U^f_E - \mu C'(E) = 0 \qquad (12.19)$$
$$\frac{\partial L}{\partial E_f} = U_{E_f} + \lambda U^f_{E_f} - \mu C'_f(E_f) = 0$$

- Eliminating μ from (12.18) we obtain $\lambda = U_z / U^f_{z_f}$.



12.2 Commodity Transfer

- Substituting $\lambda = U_z / U^f_{z_f}$ for λ into

$$\frac{\partial L}{\partial E} = U_E + \lambda U^f_E - \mu C'(E) = 0 \qquad (12.19)$$

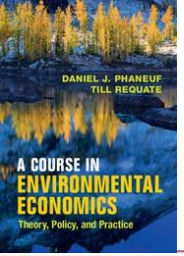
$$\frac{\partial L}{\partial E_f} = U_{E_f} + \lambda U^f_{E_f} - \mu C'_f(E_f) = 0$$

and using $\mu = U_z$ from (12.18) we obtain, after some rearranging, for the home country

$$-C'(E^*) = -\frac{U_E}{U_z} - \frac{U^f_E}{U^f_{z_f}} \qquad (12.20)$$

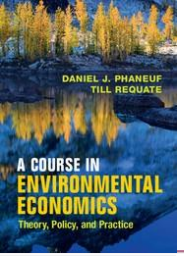
and for the foreign country

$$-C'_f(E^*_f) = -\frac{U_{E_f}}{U_z} - \frac{U^f_{E_f}}{U^f_{z_f}} \qquad (12.21)$$



12.2 Commodity Transfer

- These conditions point out that, in both countries, the marginal abatement cost should equal the sum of the two representative individuals' marginal rates of substitution between emissions reduction (the public good) and private consumption.
- This is the familiar Lindahl-Samuelson condition from lecture 1.
- Note that the marginal abatement costs need not be equal across countries, if the mutual impacts of pollution are sufficiently asymmetric.



12.2 Commodity Transfer

- In the special case of a homogeneous global pollutant we have

$$U_E = U_{E_f} \qquad (12.22)$$

$$U_E^f = U_{E_f}^f$$

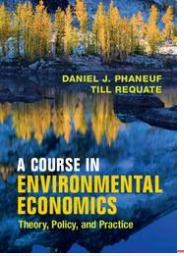
meaning the marginal disutility of pollution is equal, irrespective of where the emission originates.

- In this case, the right hand sides are identical of

$$-C'(E^*) = -\frac{U_E}{U_z} - \frac{U_E^f}{U_{z_f}^f} \qquad (12.20)$$

$$-C_f'(E_f^*) = -\frac{U_{E_f}}{U_z} - \frac{U_{E_f}^f}{U_{z_f}^f} \qquad (12.21)$$

- At the efficient allocation, the marginal abatement costs should be equal across countries.



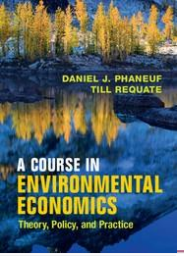
12.2 Commodity Transfer

Decentralization Through Policy Instruments

- When product markets are competitive, let E^C and E_f^C be the solutions to

$$-C'(E^C) = -\frac{U_E}{U_z} - \frac{U_E^f}{U_{z_f}^f} \tag{12.20}$$

$$-C_f'(E_f^C) = -\frac{U_{E_f}}{U_z} - \frac{U_{E_f}^f}{U_{z_f}^f} \tag{12.21}$$



12.2 Commodity Transfer

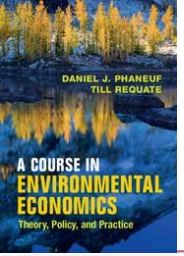
- These can be achieved when the two countries set emission taxes according to the generalized Pigouvian rules:

- For the home country and foreign country

$$\tau = -\frac{U_E(z^C, E^C, E_f^C)}{U_z(z^C, E^C, E_f^C)} - \frac{U_E^f(z_f^C, E^C, E_f^C)}{U_{z_f}^f(z_f^C, E^C, E_f^C)} \tag{12.23}$$

$$\tau_f = -\frac{U_{E_f}(z^C, E^C, E_f^C)}{U_z(z^C, E^C, E_f^C)} - \frac{U_{E_f}^f(z_f^C, E^C, E_f^C)}{U_{z_f}^f(z_f^C, E^C, E_f^C)} \tag{12.24}$$

- The home tax rate is set equal to the aggregate marginal willingness to pay to reduce an emission originating from the home country.



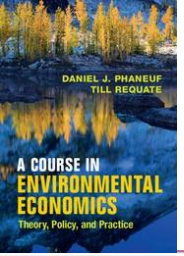
12.2 Commodity Transfer

- Since a representative producer in each country sets its marginal abatement cost equal to the tax rate, we have $-C'(E) = \tau$ and $-C'_f(E_f) = \tau_f$ and the conditions in (12.20) and (12.21) are satisfied.

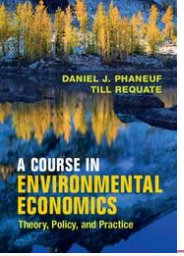
- As an alternative, the two countries can initiate cap and trade programs with emission permits given by $L = E^C$ and $L_f = E_f^C$.

- For a homogenous global pollutant, the optimal emission taxes must be equal across the countries.

- In this case, a global cap and trade system may be easier to implement, where the total permit supply must satisfy $L + L_f = E^C + E_f^C$.



12.3 Multiple Commodities and Proper Trade

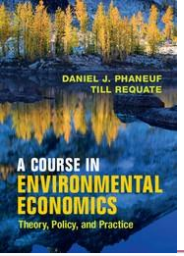


12.3.1 Model Extension

- Assume there is a representative firm in the home and foreign countries that produces a polluting good along with emissions.
- As now open economies are considered, it is necessary to distinguish production of the good from its consumption.
- In an open economy with transboundary pollution the utility of the representative consumer in the home country is given by

$$U(c,z,e,e_f) = u(c) + z - D(e,e_f) \qquad (12.25)$$
$$\equiv \int_0^c P(t)dt + z - D(e,e_f)$$

where c is consumption of the polluting good, $P(.) = U_c$ is the home country inverse demand function for that good, and $z = y - C(x,e) + p * [x - c]$ is consumption of the numeraire good z, with initial income y, and *p*=international price for the traded good.



12.3.1 Model Extension

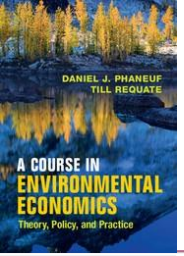
- Substituting z into (12.25), we can write the welfare function for the home country as

$$W(x,c,e,e_f) \equiv \int_0^c P(t)dt - C(x,e) - D(e,e_f) + p \cdot [x - c] \qquad (12.26)$$

where the constant y has been dropped.

- The welfare function for the *foreign country* can be re-written as

$$W^f(x_f,c_f,e,e_f) \equiv \int_0^{c_f} P_f(t)dt - C^f(x_f,e_f) - D^f(e,e_f) + p \cdot [x_f - c_f] \qquad (12.27)$$



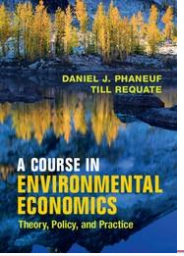
12.3.2 Efficient Allocation

- An efficient allocation must satisfy two sets of conditions:
- First, consumers' marginal willingness to pay for the polluting good must be equal to the marginal cost of production, and the latter must be equal across countries.

$$P(c) = P_f(c_f) = C_x(x,e) = C^f_{x_f}(x_f, e_f) \tag{12.28}$$

- For emission levels, the familiar Lindahl-Samuelson conditions must hold for each of countries' emission choices:

$$\begin{aligned} -C_e(x,e) &= D_e(e,e_f) + D^f_e(e,e_f) \\ -C^f_{e_f}(x_f,e_f) &= D_{e_f}(e,e_f) + D^f_{e_f}(e,e_f) \end{aligned} \tag{12.29}$$



12.3.2 Efficient Allocation

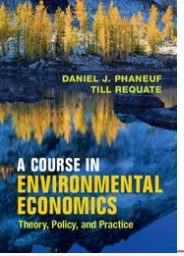
- If the pollutant is not homogeneous, and one country is more affected by pollution than another, marginal abatement costs in the cooperative solution may be different across countries.

- If the pollutant is globally homogeneous, the damage functions can be written as

$$D(e,e_f) = D(E) \qquad (12.30)$$

$$D^f(e,e_f) = D_f(E)$$

- For a globally homogenous pollutant marginal abatement costs should be equal across countries, since the location of an individual emission is irrelevant.



12.3.2 Efficient Allocation

Decentralization

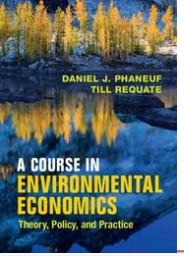
- For heterogeneous pollutants, differentiated emissions taxes are set according to

$$\tau = D_e(e,e_f) + D_e^f(e,e_f) \qquad (12.31)$$
$$\tau_f = D_{e_f}(e,e_f) + D_{e_f}^f(e,e_f)$$

- The profit functions for the home and foreign firms are $\Pi(x,e) = px - C(x,e) - \tau e$ and $\Pi_f(x_f,e_f) = px_f - C^f(x_f,e_f) - \tau_f e_f$ respectively.

- Profit maximization by both firms leads to

$$p = C_x(x,e) = C_{x_f}^f(x_f,e_f) \qquad (12.32)$$
$$\tau = C_e(x,e)$$
$$\tau_f = C_{e_f}^f(x_f,e_f)$$



12.3.3 Unilateral Environmental Policy in a Small Open Economy

- Assume that the home government regulates pollution by an emission tax, and write welfare as a function of the domestic tax rate

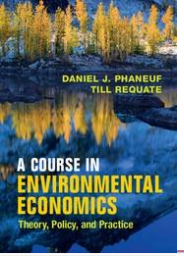
$$W(\tau) = \int_0^c P(t)dt - C(x,e) + p \cdot [x - c] - D(e,e_f) \qquad (12.33)$$

- x and e are endogenous.

- To determine the unilaterally optimal home country emission tax, we differentiate with respect to τ and obtain

$$W'(\tau) = \underbrace{\left(P(c) - p\right)}_{0}\frac{dc}{d\tau} + \underbrace{\left(p - C_x(x,e)\right)}_{0}\frac{dx}{d\tau} + \left[\underbrace{-C_e(x,e)}_{\tau} - D_e(e,e_f)\right]\frac{de}{d\tau} \qquad (12.34)$$

$$-D_{e_f}(e,e_f)\frac{de_f}{d\tau} = 0$$



12.3.3 Unilateral Environmental Policy in a Small Open Economy

- Since $-C_e(x,e) = \tau$ from the profit maximization conditions,

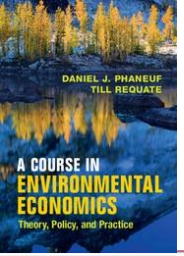
$$W'(\tau) = \underbrace{\left(P(c)-p\right)}_{0}\frac{dc}{d\tau} + \underbrace{\left(p - C_x(x,e)\right)}_{0}\frac{dx}{d\tau} + \left[\underbrace{-C_e(x,e)}_{\tau} - D_e(e,e_f)\right]\frac{de}{d\tau} \qquad (12.34)$$

$$-D_{e_f}(e,e_f)\frac{de_f}{d\tau} = 0$$

reduces to

$$\left(\tau - D_e(e,e_f)\right)\frac{de}{d\tau} = 0 \qquad (12.35)$$

- As $\frac{de}{d\tau} < 0$, we obtain $\tau = D_e(e,e_f)$.

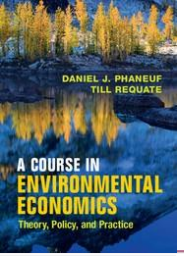


Proposition 12.1

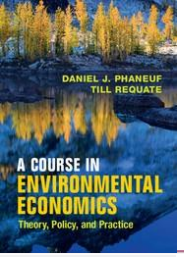
In a small open economy with only home pollution, such that $D_{e_f}(e, e_f) = 0$ *and* $D_e^f(e, e_f) = 0$ *a unilaterally optimal emission tax fully internalizes the externality.*

When there is transboundary pollution, such that $D_{e_f}(e, e_f) > 0$ *and/or* $D_e^f(e, e_f) > 0$*, the unilaterally optimal emission tax internalizes all domestic environmental damage, but does not account for the externalities imposed on foreign countries, or the impact of foreign emissions on the home country.*

International competition in this model does not provide a rational reason to 'race to the bottom'.

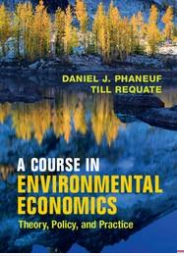


Large open Economies



12.4 Large open Economies

- The choice of optimal unilateral domestic environmental policy depends on how the foreign country manages its emissions.
- Consider two major cases:
- (a) the foreign country uses an emission tax (with a zero tax rate as a special case); and
- (b) the foreign country sets an emissions cap.



12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

Equilibrium When Both Countries Use an Emission Tax

- The competitive market equilibrium of our stylized world economy is determined by utility maximization of home and foreign consumers, so that

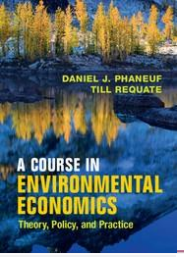
$$P(c) = p \qquad (12.36)$$
$$P_f(c_f) = p$$

and profit maximization by the home and foreign firms:

$$p = C_x(x,e) \qquad (12.37)$$
$$\tau = -C_e(x,e)$$

and

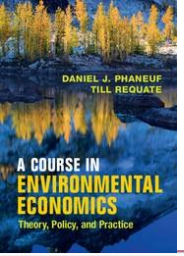
$$p = C^f_{x_f}(x_f,e_f) \qquad (12.38)$$
$$\tau_f = -C^f_{e_f}(x_f,e_f)$$



12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

- In addition, the market for the polluting good must clear, so that

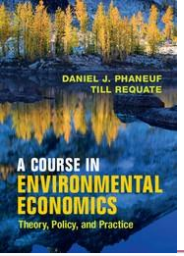
$$x + x^f = c + c^f \tag{12.39}$$



Proposition 12.2

The responses of the equation system (12.36) through (12.39) to a change in the home emission tax rate are:

- $\frac{dc}{d\tau} < 0, \frac{dc_f}{d\tau} < 0;$
- $\frac{dx}{d\tau} < 0, \frac{dx_f}{d\tau} > 0;$
- $\frac{de}{d\tau} < 0, \frac{de_f}{d\tau} > 0;$ and
- $\frac{dp}{d\tau} > 0,$

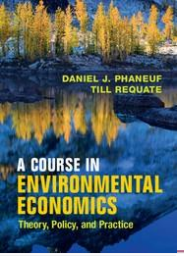


12.2 Example

- Fischer and Fox (2012) use a CGE model of global trade to simulate the effect of a unilateral carbon dioxide tax of $14 per ton on several energy and manufacturing sectors in the United States.

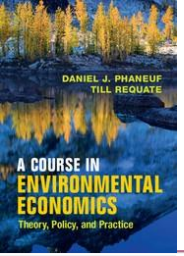
- The largest emissions reductions occur in the electricity sector, and leakage is modest – about 5 percent, as there is relatively little trade in electricity.

- In energy-intensive manufacturing, however, leakage is more substantial, given the exposure of these industries to international competition (the iron and steel sector leakage rate is 58 percent).



12.3 Example

- Aichele and Felbermayr (2012) econometrically examine carbon leakage in the context of the Kyoto agreement.
- They find on average that membership in Kyoto caused a 7 percent reduction in emissions in signatory countries.
- However, Kyoto ratification caused no change in a nation's carbon footprint, meaning the decrease in emissions was offset by an increase in the carbon intensity of imports.
- Emission reductions within the Kyoto countries relocated to non-Kyoto countries, and the overall consumption of carbon emissions remained unchanged (leakage nearly total).



12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

The Unilaterally Optimal Tax Rate

- The Welfare can be written as

$$W(\tau) = \int_0^c P(z)dz - C(x,e) + p \cdot [x - c] - D(e,e_f) \qquad (12.40)$$

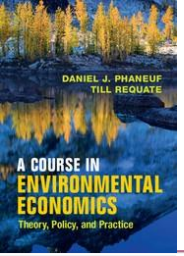
- Differentiating with respect to τ yields

$$W'(\tau) = \left(\underbrace{P(c) - p}_{0} \right) \frac{dc}{d\tau} + \left(\underbrace{p - C_x(x,e)}_{0} \right) \frac{dx}{d\tau} \qquad (12.41)$$

$$+ \left(\underbrace{-C_e(x,e)}_{\tau} - D_e(e,e_f) \right) \frac{de}{d\tau} - D_{e_f}(e,e_f) \frac{de_f}{d\tau} + \frac{dp}{d\tau}[x - c] = 0$$

- Using the behavioral conditions for utility and profit maximization, this expression reduces to

$$(\tau - D_e(e,e_f)) \frac{de}{d\tau} - D_{e_f}(e,e_f) \frac{de_f}{d\tau} + \frac{dp}{d\tau}[x - c] = 0 \qquad (12.42)$$



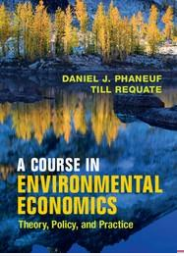
12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

$$\left(\tau - D_e(e,e_f)\right)\frac{de}{d\tau} - D_{e_f}(e,e_f)\frac{de_f}{d\tau} + \frac{dp}{d\tau}[x-c] = 0 \qquad (12.42)$$

from which the optimal unilateral domestic tax can be characterized as

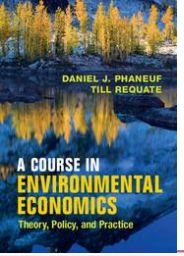
$$\tau = D_e(e,e_f) + D_{e_f}(e,e_f)\frac{de_f/d\tau}{de/d\tau} - \frac{dp/d\tau}{de/d\tau}[x-c] \qquad (12.43)$$

- The unilaterally optimal tax rate can be decomposed into three effects.



12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

- First part is $D_e(e, e_f)$ which accounts for the marginal damage to the domestic consumer, caused by domestic emissions.
- The second term $D_{e_f}(e, e_f)$ accounts for the fact that foreign pollution is affected indirectly by domestic environmental policy, through the channel of the market price of the polluting good.
- The 'not-in-my-backyard (NIMBY)' effect reflects the desire on the part of the domestic regulator to avoid simply replacing damages from the home country's emissions, with damages from foreign emissions.
- The third term is the terms-of-trade effect, which captures the impact on net exports/imports.



12.4.1 Optimal Unilateral Policy with a Foreign Emission Tax

- It is often argued that international export competition forces governments to engage into a ‘race to the bottom’ regarding environmental regulation.
- In this model, the contrary is true if the terms-of-trade motive is analyzed in isolation:
- Countries over- internalize to improve their terms of trade.