Environmental Economics - 4910

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Environmental Problems

- Overusing/exploiting renewable and exhaustible resources
- Land use changes (e.g. tropical deforestation)
- Waste (e.g. hazardous, or plastic)
- Water (over-usage, or contamination)
- Air (particles, NO_x, acid rain; ozone layer)
- Greenhouse gases (e.g., CO_2)

Classifications

- National vs. international
- Political vs. marked-based
- Number of sources and number of affected parties
- Tangible vs. nonverifiable pollutants
- Affecting producers vs consumers
- Flow pollutants vs. accumulated stocks
- Contemporary vs. long-term effects

Outline

1. Welfare theorems and market failures (micro)
2. Policy instruments (Pigou, Coase, Weitzman) (public ec.)
3. Trade and the environment (int. trade)
4. Self-enforcing vs. binding agreements (game theory)
5. Architectures for agreements (economic systems)
6. Free-riding and participation (contract theory)
7. Supply-side environmental policy (resource ec.)
8. Deforestation and REDD contracts (development ec.)
9. The value of the Future: Discounting (behavioral ec.)
10. Integrated Assessment Models (Traeger) (macro)

Consumption and Production: "ECON 101"

- Consumers i's utility and good j's production function:

$$u^i\left(x_1^i,...,x_J^i\right) \text{ and } \sum_i x_j^i \leq f^j\left(y_j^1,...,y_j^K\right),$$

- ...where $i \in \{1,...,I\}$ consumes x_j^i of good $j \in \{1,...,J\}$, and y_j^k is the quantity of input $k \in \{1,...,K\}$ used in the production of good j.
- **Pareto optimality** (PO) requires that

$$\max_{\{x_j^i\},\{y_j^k\}} u^1\left(x_1^1,...,x_J^1\right) \text{ s.t.}$$

$$\begin{aligned}
u^i\left(x_1^i,...,x_J^i\right) &\geq \overline{u}^i, \forall i && \text{(shadow value: } \lambda_i\text{)},\\
\sum_i x_j^i &\leq f^j\left(y_j^1,...,y_j^K\right) \quad \forall j && \text{(shadow value: } \mu_j\text{)},\\
\sum_j y_j^k &\leq \overline{y}^k \quad \forall k && \text{(shadow value: } \eta_k\text{)}.
\end{aligned}$$

for some default levels ($\overline{u}^i$'s) and input quantities ($\overline{y}^k$'s).

- *Do we need to include labor/leisure in the model?*

Consumption and Production: Pareto Optimality

- Lagrange (/Kuhn-Tucker) problem with foc for x_j^i and y_j^k (if $\lambda_1 \equiv 1$):

$$\begin{aligned} \lambda_i u_j^i &= \mu_j, \\ \mu_j f_k^j &= \eta_k. \end{aligned}$$

- The shadow values depend on the default levels; the $\overline{u}_i$'s.
- For PO, it is sufficient that the foc's hold for *some* shadow values.
- When the foc's are combined:

$$\begin{aligned} \frac{u_j^i}{u_{j'}^i} &= \frac{\mu_j}{\mu_{j'}} = \frac{u_k^{i'}}{u_l^{i'}} \ \forall \left(i, i'\right), \left(j, j'\right) \quad \text{(efficiency in consumption)}, \\ \frac{f_k^j}{f_{k'}^j} &= \frac{\eta_k}{\eta_{k'}} = \frac{f_k^{j'}}{f_{k'}^{j'}} \ \forall \left(k, k'\right), \left(j, j'\right) \quad \text{(efficiency in production)}, \\ \frac{u_j^i}{u_{j'}^i} &= \frac{f_k^{j'}}{f_k^j} \ \forall \left(j, j'\right), i, k \quad \text{(efficiency in exchange)}. \end{aligned}$$

Consumption and Production: Market Equilibrium

- Consumers' choice, given endowment E^i (with shadow-value ν_i):

$$\max_{\left\{x_j^i\right\}_j} u^i\left(x_1^i, ..., x_J^i\right) \text{ s.t. } \sum_j p_j x_j^i \leq E^i \quad (\nu_i) \Rightarrow u_j^i = \nu_i p_j.$$

- Producers:

$$\max p_j f^j\left(y_j^1, ..., y_j^K\right) - \sum_k w^k y_j^k \Rightarrow p_j f_k^j = w^k.$$

- Combined:

$$\begin{aligned}
\frac{u_j^i}{u_{j'}^i} &= \frac{\mu_j}{\mu_{j'}} = \frac{u_j^{i'}}{u_{j'}^{i'}} \text{ if just } \mu_j = p_j, \\
\frac{f_k^j}{f_{k'}^j} &= \frac{\eta_k}{\eta_{k'}} = \frac{f_k^{j'}}{f_{k'}^{j'}} \text{ if just } \eta_k = w^k, \\
\frac{u_j^i}{u_{j'}^i} &= \frac{f_k^{j'}}{f_k^j} = \frac{p_j}{p_{j'}} \ \forall\left(j, j'\right), i, k.
\end{aligned}$$

Consumption and Production: Welfare Theorems

Theorem

1. *Every market equilibrium $\Rightarrow$ Pareto optimal.*
2. *Every Pareto optimal outcome $\Rightarrow$ market equilibrium – given some allocation of endowments.*

- Where is the environment?

Consumption and Production: With Externalities

- Externalities from inputs/productions to consumers:

$$u^i\left(x_1^i, ..., x_J^i, \sum_j g_j\right) \text{ and } \sum_i x_j^i \leq f^j\left(y_j^1, ..., y_j^K, g_j\right).$$

- Pareto Optimality is given by the same conditions as above, plus:

$$\mu_j f_g^j = \sum_i \lambda_i \left(-u_g^i\right) \Rightarrow u_j^1 f_g^j = \sum_i u_j^1 \frac{-u_g^i}{u_j^i} \Rightarrow f_g^j = \sum_i \frac{-u_g^i}{u_j^i}.$$

- Equilibrium with no regulation: j emits until $f_g^j = 0$.
- With regulation or tax t_g^j on j's emission: $p_j f_g^j = t_g^j$
- This coincides with the PO outcome if

$$f_g^j = \frac{t_g^j}{p_j} = \sum_i \frac{-u_g^i}{u_j^i} = \sum_i \frac{-u_g^i}{p_j u_1^i / p_1} \Rightarrow t_g^j = \sum_i \frac{-u_g^i}{u_1^i} p_1.$$

- So, the emission **tax should be the same for all firms**, no matter how valuable/dirty they are.

Consumption and Production: With Externalities (cont.)

- If good 1 is a numeraire good (i.e., if $u_1^i = 1 = p_1$), then $t_g^j = \sum_i u_g^i$.
- Alternatively, the regulator may decide on the g_j's directly.
- For each such policy, there will be equilibrium prices and quantities such that payoffs are functions $u_i(\mathbf{g})$ and profits $\pi_j(\mathbf{g})$.
- Larger g_j's is likely to benefit producer j $(B_j(g_j))$ but be costly for consumers $(C_i(g_j))$.

Externalities and Public Goods

- Let g_i be emission by *agent* $i \in N \equiv \{1, ..., n\}$, and $\mathbf{g} = \{g_1, ..., g_n\}$.
- **Externalities:**

$$u_i(\mathbf{g}), \text{ if } \partial u_i / \partial g_j \neq 0 \text{ for some } j \neq i.$$

- **Public good/bad:**

$$u_i(\mathbf{g}) = u_i(g_i, G) = B_i(g_i) - C_i(G), \text{ where } G = \sum_{j \in N} g_j.$$

- To get a unique solution, assume u_i is concave in g_i
  - For example: Every B_i is concave while C_i is convex.
- **Business as usual** (interior) equilibrium:

$$B_i'(g_i) = C_i'(G).$$

- Suppose transfers enter linearly and additively in u_i.
- **The first-best** (FB; the unique PO outcome with transfers):

$$B_i'(g_i^*) = \sum_{j \in N} C_j'(G^*).$$

Pigou Taxes (The "Incorrect Prices" Approach)

- Suppose i pays $t_i g_i$ and receives $T_i(\mathbf{g})$.
- Then, in equilibrium:

$$\frac{\partial B_i(g_i)}{\partial g_i} = C_i'(G) + t_i - \frac{\partial T_i(\mathbf{g})}{\partial g_i}.$$

  - Equivalent: A *subsidy* $T_i(\mathbf{g}) - t_i g_i$, f.ex. $t_i \cdot (\overline{g}_i - g_i)$.
- This coincides with the first-best if e.g.:

$$t_i = \sum_{j \in N \setminus i} C_j'(G) \text{ and } \frac{\partial T_i(\mathbf{g})}{\partial g_i} = 0.$$

- In principle, it is (almost) irrelevant how tax revenues are spent.
  - For example: $T_i(\mathbf{g}) = \sum_{j \in N \setminus i} t_j g_j / (n-1)$.
- If $C_i' \approx 0$ for each emitter, the linear tax is the same for all:

$$t = \sum_{j \in N} C_j'(G^*) \Rightarrow B_i'(g_i) = \sum_{j \in N} C_j'(G^*).$$

Pigou Taxes - Uncertainty

- Facing the same tax, we get:

$$B_i'\left(g_i, \epsilon_i\right) = t = B_j'\left(g_j, \epsilon_j\right) \forall \left(i, j\right) \in N^2$$

even if individual shocks $\left(\epsilon_i\right)$ are private information.

- Then, define $\boldsymbol{\epsilon} = \left(\epsilon_1, ..., \epsilon_n\right)$ and

$$B\left(t, \boldsymbol{\epsilon}\right) \equiv \sum_{i \in N} B_i\left(B_i'^{-1}\left(t, \epsilon_i\right), \epsilon_i\right).$$

- The optimal tax is given by:

$$\max_t \mathrm{E}\left[B\left(t, \boldsymbol{\epsilon}\right) - C\left(\sum_{i \in N} B_i'^{-1}\left(t, \epsilon_i\right)\right)\right].$$

Pigou Taxes - Uncertainty - Example Q

- Consider the quadratic approximation (Y=exp. "bliss" point):

$$B(G,\epsilon) = -\frac{b}{2}(Y - G - \epsilon)^2 \text{ and } C(G) = \frac{c}{2}G^2,$$

where the aggregate shock is $\epsilon \in \mathbb{R}$, $\mathrm{E}\epsilon = 0$, and variance $\mathrm{E}\epsilon^2 = \sigma_\epsilon^2$.

- The equilibrium, given t:

$$\max_G -\frac{b}{2}(Y - G - \epsilon)^2 - tG \Rightarrow b(Y - G - \epsilon) = t.$$

- The tax pins down B' and B, leaving the uncertainty to G and $C(G)$.
- The optimal t:

$$\max_t -\frac{t^2}{2b} - \mathrm{E}\frac{c}{2}(Y - \epsilon - t/b)^2 \Rightarrow t^* = c(Y - t^*/b) = \frac{cbY}{b+c}.$$

- The uncertainty does not influence the optimal level of t. (Why?)
- **Welfare loss** relative to no uncertainty increases in c:

$$L_t^\epsilon = \frac{c\sigma_\epsilon^2}{2}.$$

Pigou Taxes and Tax Revenues

- Tax revenues (at the above optimal t^*):

$$\mathrm{E}tG = \mathrm{E}\frac{cbY}{b+c}\left(Y - \epsilon - \frac{cY}{b+c}\right) = \frac{cb^2Y^2}{b+c}.$$

- Tax revenues (at general t):

$$t\,(Y - \epsilon - t/b)$$

- Normally, revenues necessitate distortionary taxes.
- With the social value λ, the optimal t is thus:

$$\max_t -\frac{t^2}{2b} - \mathrm{E}\frac{c}{2}\,(Y - \epsilon - t/b)^2 + \mathrm{E}\lambda t\,(Y - \epsilon - t/b) \Rightarrow$$

$$t = c\,(Y - t/b) + \lambda b\,(Y - 2t/b) = \frac{cb + \lambda b^2}{b + c + 2\lambda b}Y.$$

- which can be increasing or decreasing in λ...
- RQ: (When) is there a "double dividend"?

Pigou Taxes and 'Double Dividend'

Proposition

1. *Weak form: The regulation with Pigou tax revenues raises social efficiency relatively to regulation without tax revenues.*
   - *Holds trivially*
2. *Strong form: The optimal tax is larger than the Pigovian level.*
   - *The strong form may or may not hold.*

Coase (The "Property Rights" Approach)

- Suppose disagreement leads to the "default" payoffs u_i^D. For example, u_i^D may equal $u_i\left(\mathbf{g}^{BAU}\right)$.
- To negotiate a better outcome, a "proposer", i, would prefer to:

$$\begin{aligned}\max_{\mathbf{g},\mathbf{t}} u_i &= B_i\left(g_i\right)-C_i\left(G\right)-t_i \text{ s.t.}\\ u_j &= B_j\left(g_j\right)-C_j\left(G\right)-t_j \geq u_j^D \ (\text{IR}_j).\end{aligned}$$

- With budget balance, $t_i=-\sum_{j\in N\setminus i} t_j$, so i prefers the largest t_j's satisfying IR_j.
- IR_j can be substituted into u_i, so that i maximizes:

$$\begin{aligned}\max_{\mathbf{g},\mathbf{t}} u_i &= B_i\left(g_i\right)-C_i\left(G\right)+\sum_{j\in N\setminus i}\left[B_j\left(g_j\right)-C_j\left(G\right)-u_j^D\right]\\ &= \sum_{j\in N}\left[B_j\left(g_j\right)-C_j\left(G\right)\right]-\sum_{j\in N\setminus i} u_j^D=\sum_{j\in N} u_j\left(\mathbf{g}^*\right)-\sum_{j\in N\setminus i} u_j^D.\end{aligned}$$

- In other words: i maximizes the sum of payoffs (minus a constant).
- Consequently, the proposed g_j's coincides with the first best.

Coase Theorem (1960)

Theorem

- *The parties negotiate the efficient outcome, regardless of the initial allocation of property rights (i.e., the default outcome, u_j^D) as long as there are no 'transaction costs.'*

- For example, u_j^D may reflect BAU (i.e., everyone has the "right" to emit as much as they want), or u_j^D could be $u_j(\mathbf{0})$, i.e., no-one has the right to emit anything.
- "Transaction costs" (tc_i) must be sufficiently small:

$$tc_i \leq \sum_{j \in N} \left[u_j(\mathbf{g}^*) - u_j^D \right].$$

- What is this "transaction cost"?
- To ensure an efficient outcome, the bargaining power should be given the party who faces the smallest transaction costs (i.e., the party who can easily contact others or who has most information) (RQ: Why?)

Trading Pollution Permits ("Missing Market")

- If i has the right to emit Q_i^0, while j has the right to emit Q_j^0, the two might benefit from trading without increasing total emission:

$$g_i + g_j \leq Q_i^0 + Q_j^0.$$

- That is, if i emits g_i and sell $Q_i^0 - g_i$, j can emit g_j from buying $g_j - Q_j^0 = Q_i^0 - g_i$ from i.
- This trade is beneficial as long as $B_i' < B_j'$.
- With efficient trade, $B_i' = B_j'$.
- More generally, a proposer i prefers to:

$$\begin{aligned}
\max_{\mathbf{g},\mathbf{t}} u_i &= B_i\left(g_i\right) - C_i\left(G\right) - t_i \text{ s.t.} \\
u_j &= B_j\left(g_j\right) - C_j\left(G\right) - t_j \geq u_j^D \text{ (IR}_j\text{) and} \\
\sum_{j\in N} g_j &\leq \sum_{j\in N} Q_j^0 \text{ and } \sum_{j\in N} t_j \geq 0.
\end{aligned}$$

- Consequently, $B_i' = B_j'$ for all pairs (i, j)
- ...regardless of the endowments.

Perfect Pollution Markets ("Missing Market")

- If $n \longrightarrow \infty$, every i is likely to take the permit price p as given.
- If i owns Q_i^0 permits already, i solves

$$\max_{g_i} B_i\left(g_i\right) - C_i\left(G\right) - p\left(g_i - Q_i^0\right) \Rightarrow B_i'\left(g_i\right) = p,$$

  since $G = \sum_{j \in N} Q_j^0$ is independent of g_i.
- The outcome is FB if:

$$p = \sum_{j \in N} C_j'\left(G^*\right).$$

- I.e., the outcome is FB if the quantity (and thus the price) is "right", i.e., if:

$$B_i\left(g_i\right) = p = \sum_{j \in N} C_j'\left(G^*\right).$$

Perfect Pollution Markets ("Missing Market")

Proposition

- *When each emitter is a price-taker, the permit market equilibrium is efficient, regardless of the initial allocation of rights.*

- RQ: Why is the initial allocation (Q_i^0) is irrelevant?
- RQ: Is that useful for the regulator? How will the regulator decide on the initial endowments? Must Q_i^0 be exogenous?
- What if Q_i^0 depends on past production or past emissions?
- So, permit trade $=>$ FB whether $n = 2$ or $n = \infty$.
  - Should we expect FB also if $n \in (2, \infty)$? Why/why not?
- With heterogeneous pollutants (i.e., $G = \sum_{j \in N} h_j g_j$, the FB requires:

$$B_i'(g_i) = pq_i = \sum_{j \in N} h_i C_j'(G^*), \text{ so } \frac{q_i}{q_j} = \frac{h_i}{h_j} \; \forall (i,j) \in N^2.$$

Perfect Pollution Markets - Uncertainty

- Private information: Conditions above (when $n = \infty$) hold if $B_i = B_i(g_i, \epsilon_i)$ and ϵ_i is i's private information.
- Total benefit in equilibrium is:

$$B(G, \boldsymbol{\epsilon}) = \max_{\mathbf{g}} \sum_{j \in N} B_j(g_j, \epsilon_j) \text{ s.t. } \sum_{j \in N} g_j = G.$$

- The optimal cap is

$$\max_G \mathrm{E}B(G, \boldsymbol{\epsilon}) - C(G) \Rightarrow \mathrm{E}B'(G, \boldsymbol{\epsilon}) = C'(G).$$

- Example Q (with a single aggregate shock $\epsilon \in \mathbb{R}$):

$$\mathrm{E}b(Y - G + \epsilon) = cG \Rightarrow G^* = \frac{b}{c+b}Y.$$

- The shock does not affect G, but only B'.
- Relative to no uncertainty, the welfare loss is:

$$L_G^{\epsilon} = \frac{b\sigma_{\epsilon}^2}{2}.$$

Prices vs. Quantities (Weitzman '74)

Proposition

- *The efficiency loss under quotas is smaller than under prices/taxes, $L_G^\epsilon < L_t^\epsilon$, IFF $b < c$.*

- This holds generally when B and C are approximated by quadratic functions, no matter the distribution of errors, and even if there are (additive) shocks in the C function (RQ: Why?)
- Rather than comparing welfare to the situation without uncertainty, we can compare to the first-best outcome with the shock. (RQ: Why?)
- RQ: Without shocks in $B(.)$, the shock in $C(.)$ is irrelevant for the comparison, and then the slopes are also irrelevant. (Why?)
- RQ: How can the losses be reduced further?
- By hybrid schemes?
- Floor/ceiling for price?

Prices vs. Quantities: Revenues

- Pigou taxes raises revenues, which has an additional benefit.
- The willingness to pay for a quota is B', so the revenues when auctioning the initial quota endowments are:

$$\frac{b}{c+b}Yb\left(Y-\frac{b}{c+b}Y+\epsilon\right)=\frac{b^2Y}{c+b}\left(\frac{c}{c+b}Y+\epsilon\right).$$

- This has the same mean as the expected Pigou tax revenues.
- The variance of the auction revenues is smaller IFF $b<c$.
- This adds to the benefits of quotas, rather than taxes, IFF $b<c$.