Environmental Economics 4910

Bård Harstad

UiO

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Outline

a. Concepts

b. Repeated games and Folk theorem

c. Repeated games with emission and pollution

d. Continuous emission levels and policies

e. Renegotiation proofness

f. Uncertainty and imperfect public monitoring

g. Technological spillovers

h. Stocks

i. Lessons

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  - "technology needs must be nationally determined, based on national circumstances and priorities" (§114 in the Cancun Agreement, confirmed in Durban)

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  - There is no explicit sanctions
  - Compliance is the main problem

a. Important Concepts and Equilibria Refinements

Normal form game	Nash equilibrium
Extensive form game	Subgame-perfect equilibrium
Repeated game and stage game	Renegotiation proofness
Stochastic game	Markov-perfect equilibrium

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- The emission game is a prisonner dilemma game if both holds:

$$1 < \frac{B(\overline{g}) - B(\underline{g})}{c(\overline{g} - \underline{g})} < n.$$

b. The Repeated Prisonner Dilemma Game

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$$\begin{aligned} \frac{B\left(\underline{g}\right) - cn\underline{g}}{1-\delta} &\geq B\left(\overline{g}\right) - c\overline{g} - c\left(n-1\right)\underline{g} + \delta\frac{B\left(\overline{g}\right) - cn\overline{g}}{1-\delta} \Leftrightarrow \\ B\left(\overline{g}\right) - B\left(\underline{g}\right) &\leq c\left(\overline{g} - \underline{g}\right)\left[\delta n + \left(1-\delta\right)\right] \end{aligned}$$

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- So, as long as the first best requires $g = \underline{g}$, cooperation is possible for sufficiently high discount factors:

$$\delta \geq \widehat{\delta} \equiv \frac{1}{n-1}\left[\frac{B\left(\overline{g}\right) - B\left(\underline{g}\right)}{c\left(\overline{g} - \underline{g}\right)} - 1\right] < 1.$$

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- If $\delta < \widehat{\delta}$, the unique SPE is $g = \overline{g}$.

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- Consider next a stage game with both emissions and technology investments $(r_{i,t})$:

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- Will be added below: Heterogeneity, continuous g, uncertainty, and stocks

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- Given g, every country will voluntarily invest optimally in r.
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- With such commitments, the first-best agreement is simply $g = \underline{g}$.

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- subject to the two "compliance constraints" (CC^r) and (CC^g):

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- Literature says little when $\delta < \max\left\{\widehat{\delta}^r, \widehat{\delta}^g\right\}$.

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- CC^g is more likely to hold for large δ, n, or $c(r)$.
- Maximizing lhs of CC^g wrt r gives the 'best' compliance technology $\widehat{r}$:

$$\begin{aligned}\frac{B_r(\underline{g}, \widehat{r}) - n\underline{g}c_r(\widehat{r}) - k}{1/\delta - 1} &= B_r(\overline{g}, \widehat{r}) - B_r(\underline{g}, \widehat{r}) - (\overline{g} - \underline{g})\, c_r(\widehat{r}) \\ &\approx (\overline{g} - \underline{g})\left[B_{gr} - c_r\right] \Leftrightarrow \\ \widehat{r} &> r^* \text{ IFF } B_{gr} - c_r < 0.\end{aligned}$$

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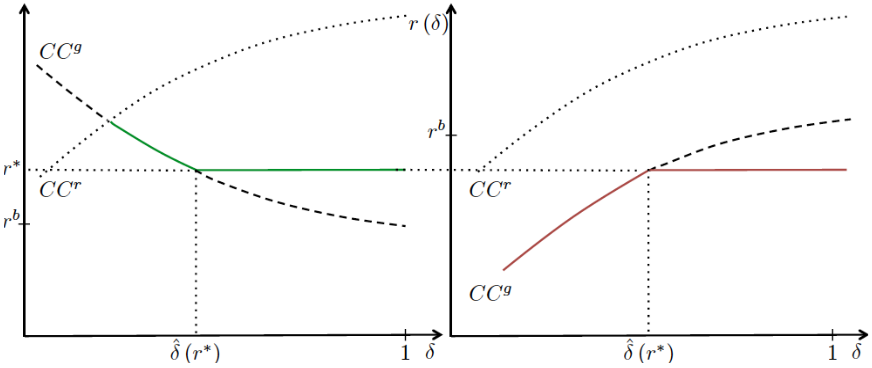

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- However, the harder problem is to ensure that they are willing to *comply* - once they expect others to comply.
- Reluctant countries should be helped to make such **self-commitment**, and this can be done with technology!

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- Green technologies and adaptation technologies are strategic **complements**: The more countries adapt, the more they must invest in green technologies.
- Brown technologies and adaptation technologies are strategic **substitutes**: The more countries invest in brown technologies, the less they should adapt.

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- Either effect may be strongest.

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- Let the investment-cost be $\frac{k}{2} r_i^2$.
- We can define $d_i \equiv Y - y_i$, so that $g_i = Y - d_i - r_i$, and $B = -\frac{b}{2} d_i^2$.

d. Continuous emission levels - First Best

- The socially optimal decisions are:

$$\begin{aligned} bd &= b\left(Y - r - g\right) = cn \Rightarrow g^*\left(r\right) = Y - r - \frac{cn}{b} \\ kr &= cn = bd = b\left(Y - r - g\right) \Rightarrow r^*\left(g\right) = \frac{b\left(Y - g\right)}{k + b}. \end{aligned}$$

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- Combined, the first-best is

$$g^* = Y - \frac{cn}{b} - \frac{cn}{k} \text{ and } r^* = \frac{cn}{k}.$$

d. Continuous emission levels - BAU

- The Nash equilibrium/BAU of the stage game is:

$$bd = c \text{ and } kr = c = bd \text{, so}$$

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- This gives the BAU payoff:

$$V^b = \frac{\frac{c^2}{b}\left(n - \frac{1}{2}\right) + \frac{c^2}{k}\left(n - \frac{1}{2}\right) - cnY}{1 - \delta}.$$

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- An equilibrium gives:

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- Thus, $r^e > r^*\left(g^e\right)$, and countries over-invest conditional on g.

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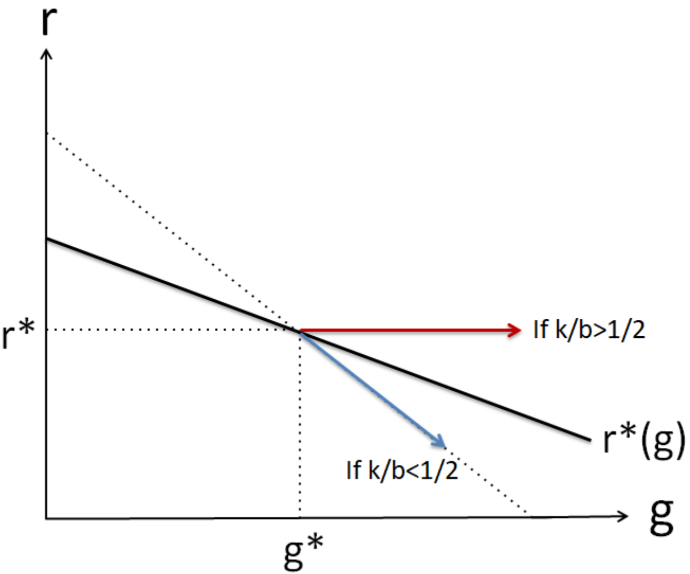

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- To ensure that $kr = cn$, $\varsigma = cn - \tau > 0$ decreases in $\delta \in \left(\overline{\delta}^r, \overline{\delta}^g\right)$.

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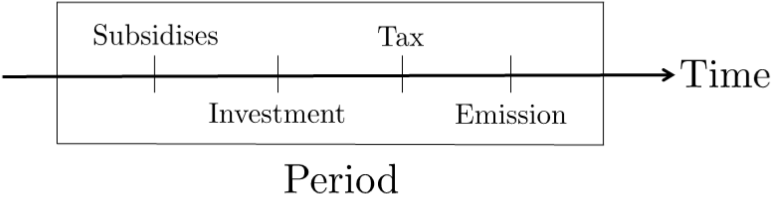

d. Carbon Taxes and Investment Subsidies

- Investment subsidy ς_i set before the investment stage and emission tax τ_i set before the emission stage by each country.
- International agreement: Defines taxes/subsidies to implement the best SPE.
- τ_i does not affect (CC_i^g), while ς_i relaxes (CC_i^r).

Corollary

When δ declines from one, (CC_i^g) is always the first compliance constraint to bind;

ii. *If $\delta \geq \overline{\delta}^g$, the outcome is first best and implemented by $\tau_i = cn$ and $\varsigma_i = 0$;*

iii. *If $\delta < \overline{\delta}^g$, the best SPE is implemented by $\tau_i = cn - \phi(\delta)$ and $\varsigma_i = \phi(\delta)$ with $\phi'(\delta) < 0$.*

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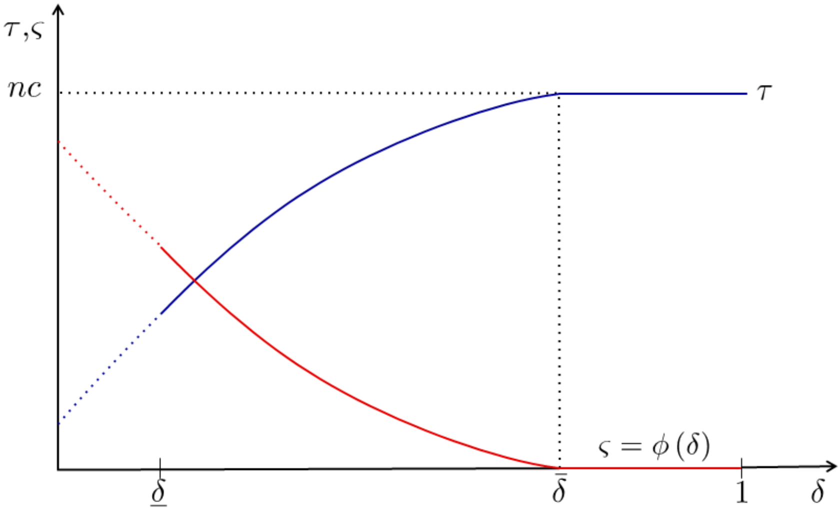

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- **Definition.** A subgame-perfect equilibrium $s^t \in S^w$ is *strongly renegotiation proof* if no continuation payoff profile is strictly Pareto-dominated by the continuation payoff profile of another $s' \in S^w$.

e. Renegotiation-Proofness: Consequences

Proposition

Suppose that after a country deviates, the countries can renegotiate before triggering the penalty.

i. *With strong renegotiation-proofness (or with side transfers) and if a deviator has no bargaining power, the coalition of punishers will ensure that the deviator does not receive more than the BAU continuation value:*
   - *permitting renegotiation does not alter the set of Pareto optimal SPE;*

ii. *With weak renegotiation-proofness, or if a deviator has some bargaining power, it will receive more than its BAU continuation value and the compliance constraint is harder to satisfy than without renegotiation:*
   - *to satisfy the compliance constraint* $|r_i - r^*|$ *must increase more, the larger the bargaining power.*

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- The probabilities will depend on the threshold $\widehat{g}$:

$$p_I = 1 - F\left(\widehat{g} - n\underline{g}\right) \text{ and } p_{II} = F\left(\widehat{g} - (n-1)\,\underline{g} - \overline{g}\right)$$

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- When $p_l > 0$, the best SPE may require $T < \infty$.

f. Uncertainty and Imperfect Monitoring: Cooperation

Proposition

- *The triplet* $\left(\underline{g}, r, T\right)$ *is an SPE if* $\delta \geq \widehat{\delta}\left(r, T\right)$ *where* $\widehat{\delta}_T < 0$, $\widehat{\delta}_{p_I} > 0$, $\widehat{\delta}_{p_{II}} > 0$ *and, as before,* $\widehat{\delta}_n < 0$, $\widehat{\delta}_h < 0$ *and*

$$sign\ \widehat{\delta}_r = sign\ \left(B_{gr} - c_r\right).$$

f. Uncertainty and Imperfect Monitoring: Proof

- *Proof:* Let $V^c(r)$ be the continuation value in the cooperation phase:

$$V^c(r) = B\left(r, \underline{g}\right) - n\underline{g}c(r) - kr + \delta\left[p_l V^p(r) + (1 - p_l)\, v^c(r)\right],$$

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- where the continuation value at the start of the punishment phase is:

$$\begin{aligned} V^p(r) &= \sum_{\tau=0}^{T-1} \delta^\tau v^b + \delta^T V^c(r) = \frac{1-\delta^T}{1-\delta} v^b + \delta^T V^c(r), \text{ where} \\ v^b &= \max_r B(r, \bar{g}) - n\bar{g}c(r) - kr. \end{aligned}$$

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- As before, if the agreement is valuable, CC-r is never binding.

f. Uncertainty and Imperfect Monitoring: Proof

A country may be tempted to pollute a lot to get $V^d(r) =$

$$B(r,\bar{g}) - \left[(n-1)\underline{g} + \bar{g}\right] c(r) - kr + \delta\left[(1-p_{II}) V^p(r) + p_{II} V^c(r)\right]$$

The best equilibrium maximizes $V^c(r)$ subject to CC-g:

$$V^c(r) \geq V^d(r) \Rightarrow \qquad \text{(CC–im)}$$

$$V^c(r)\left[(1-p_{II}-p_I)\delta\left(1-\delta^T\right)+1-\delta\right] \geq$$
$$B(r,\bar{g}) - \left[\bar{g}+(n-1)\underline{g}\right]c(r) - kr + (1-p_{II}-p_I)\delta\left(1-\delta^T\right)V^b,$$

Let $\widehat{\delta}(r, T, p_{II}, p_I)$ be defined such that the inequality holds with identity. Doing comparative static w.r.t. this equation completes the proof.

f. Uncertainty and Imperfect Monitoring: r vs. T

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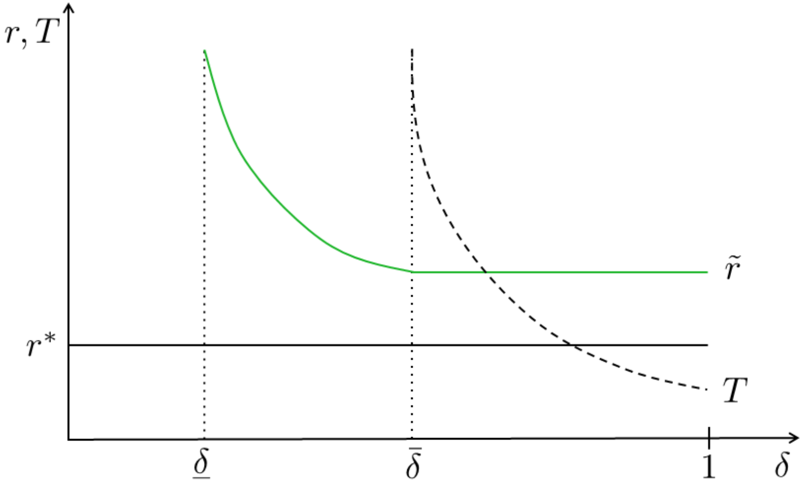

f. Uncertainty and Imperfect Monitoring

- Let θ_t be drawn from a cdf $\Phi(\cdot)$ with variance σ^2 and zero mean defined over a finite support, and measures the net emission from Nature.
- Let $\phi(y|g)$ be the density function of y conditioned on countries' emissions $g = y - g_0$ and assume that the monotone likelihood ratio property holds: The ratio $\phi(y|g')/\phi(y|g)$ is strictly increasing in y when $g' > g$.
- Then, it is optimal to increase $\widehat{g}$ even though T must increase also (to ∞). (This is the "bang-bang result of Abreu, Pearce, and Stacchetti '90)
- In equilibrium, the strategic value of r is that it increases $\widehat{g}$ and thus the probability p_I.

g. Technological Spillovers

- With technological spillovers, the country i's per capita utility is:

$$B\left(g_i, z_i\left(r_i, r_{-i}\right)\right) - hc\left(z_i\left(r_i, r_{-i}\right)\right)\sum g_j - kr_i$$

where

$$z_i\left(r_i, r_{-i}\right) \equiv (1-e)r_i + \frac{e}{n-1}\sum_{j\neq i} r_j$$

- The first-best r_i^* is as before, but countries will not invest optimally conditionally on g_i;
- Noncooperative investments decline in e;
- When $r_i^* > r_i^b$, countries are tempted to deviate from the first-best even at the investment stage.

g. Technological Spillovers

- At the investment stage, (CC_e^r) is:

$$\frac{v}{1-\delta} \geq \frac{e}{1-e} k \left(r - r^b \right) + \frac{v^b}{1-\delta},$$

- At the emission stage, (CC_e^g) is as before;

- Let $\widehat{\delta}^r(r)$ and $\widehat{\delta}^g(r)$ be the level of δ_i such that (CC_e^r) and (CC_e^g) holds with equality;

g. Technological Spillovers

Proposition

An SPE exists in which $g_i = \underline{g}\ \forall i \in N$ if and only if $\delta \geq \underline{\delta}$. In this case, the Pareto optimal SPE is unique and:

i *If* $\delta \geq \max\left\{\widehat{\delta}^r(r^*), \widehat{\delta}^g(r^*)\right\}$, *then* $r = r^*$;

ii. *If* $\delta \in \left[\underline{\delta}, \max\left\{\widehat{\delta}^r(r^*), \widehat{\delta}^g(r^*)\right\}\right)$, *then:*

$$r = \begin{cases} r^g(\delta) > r^* \text{ when } e \leq \overline{e} \text{ if (G);} \\ r^r(\delta) < r^* \text{ when } e > \overline{e} \text{ if (G);} \\ \min\left\{r^g(\delta), r^r(\delta)\right\} < r^* \text{ if (NG).} \end{cases}$$

Corollary

Stronger intellectual property right may be necessary to sustain a self-enforcing treaty.

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- Consider a pollution stock $G_t = q_G G_{t-1} + \sum g_{i,t}$ with marginal cost C, and a technology stock $r_{i,t} = q_R r_{i,t-1} + \Delta r_{i,t}$, where the investment $\Delta r_{i,t}$ has the marginal cost K:

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- Tech subsidies must increase if δ decreases.
- But if tech binds future emissions, investments cannot be too high.

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