Designing Emissions Trading Schemes: Negotiations on the Amount & Allocation of Permits

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Part 1: Motivation

Motivation

- "*Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen.*" (Stern 2008, p. 1)
  - Primary force preventing emissions reduction: Free-riding incentive
- Economic theory proposes **price-based** and **quantity-based** instruments as a remedy
- Building on **price-based** instruments, Weitzman (2014) explores a simple mechanism to alleviate the free-riding incentive:
  - Pairwise majority voting on the emissions price
- Does a similar mechanism exist for **quantity-based** instruments?

Part 2: Model & Basic Insights

Framework

- Consider **two countries** that emit greenhouse gases
- Each country $i \in \{1, 2\}$ carries out abatement activities a_i relative to its emissions level under "business as usual" $e_{i,0} \in \mathbb{R}_{++}$
  - Overall abatement $A := \sum_i a_i$
  - Overall emissions under "business as usual" $E_0 := \sum_i e_{i,0}$
- Country i benefits from **overall** abatement $B_i(A)$
  - a_{-i} has a positive externality on country i and vice versa
- Country i bears costs of its **own** abatement $C_i(a_i)$

Assumptions (I)

- Following the literature (e.g., Weitzman, 1974; Barrett, 1994; McGinty, 2007; Weitzman, 2014; Gersbach & Hummel, 2016), we assume quadratic abatement costs:

Assumption: Cost Function

Country i's costs are captured by a cost function $C_i : [0, e_{i,0}] \to \mathbb{R}_+$, which is of the quadratic form

$$C_i(a_i) = \frac{\zeta_i}{2} a_i^2, \quad \text{where} \quad \zeta_i > 0, \qquad i = 1, 2.$$

Assumptions (II)

- Country i's benefit function satisfies the following assumption:

Assumption: Benefit Function

Country i's benefit function $B_i : [0, E_0] \to \mathbb{R}_+$ is twice continuously differentiable, strictly increasing, strictly concave, and satisfies

$$B_i(0) = 0, \quad B_i'(0) = \infty, \quad B_i'(E_0) = 0, \quad \text{and} \quad B_i'' < -\zeta_i \zeta_{-i}^2, \quad i = 1, 2.$$

Quantity-Based Instrument: Emissions Trading

- Countries participate in a joint **cap-and-trade system** with
  - Endogenous market price p
  - Overall emissions cap $\bar{E}$
  - Share of permits allocated to country 1 $\mu_1 \in [0, 1]$

- Country i's welfare function under this scheme is:

$$B_i(A) - C_i(a_i) + (\mu_i \bar{E} - (e_{i,0} - a_i))p \qquad i = 1, 2$$

$$\textit{where} \quad \mu_1 := \mu \quad \textit{and} \quad \mu_2 := (1 - \mu)$$

Abatements & Emissions Price

- Firms **minimize their total costs** under the cap-and-trade system
- Minimization problem of a representative price-taking firm in country i is

$$\min_{0 \leq a_i \leq e_{i,0}} p \cdot (e_{i,0} - a_i) + C_i(a_i) \qquad i = 1, 2$$

- Solving the **decision problem** and taking **market clearing on the certificate market** into account yields

$$p = p(\bar{E}) := \zeta_1 \zeta_2 \left(E_0 - \bar{E}\right)$$

$$a_i = a_i(\bar{E}) := \zeta_{-i} \left(E_0 - \bar{E}\right) \qquad i = 1, 2$$

$$A = A(\bar{E}) := E_0 - \bar{E}$$

Welfare Functions

- Using $p(\bar{E})$, $a_i(\bar{E})$ and $A(\bar{E})$, country i's welfare as a function of the design of the cap-and-trade system is:

$$W_i(\bar{E}, \mu_1) := B_i(A(\bar{E})) - C_i(a_i(\bar{E})) + (\bar{E}\mu_i - e_{i,0} + a_i(\bar{E}))p(\bar{E}) \qquad i = 1, 2,$$

where $\mu_2(\mu_1) := 1 - \mu_1$

Part 3: Benchmarks

Benchmark I: Social Planner

- The **maximization problem** of the **social planner** is:

$$\max_{0 \leq \bar{E} \leq E_0} W(\bar{E}) := \sum_i W_i(\bar{E}, \mu_1) \tag{3.1}$$

- The corresponding FOC simplifies to

$$\sum_i B_i'(A(\bar{E})) = C_i'(a_i(\bar{E})) \qquad i = 1, 2 \quad (3.2)$$

Lemma 3.1

There exists a unique efficient cap $0 < \bar{E}^S < E_0$ that solves Problem (3.1). It is determined by the solution to (3.2).

Benchmark II: National Caps

- Consider national regulations in the form of **national caps $\bar{e}_i$**
- Given $\bar{e}_{-i}$, country i now chooses $\bar{e}_i$ to **maximize its welfare**, i.e., by solving

$$\max_{0 \leq \bar{e}_i \leq e_{i,0}} B_i(A(\bar{e}_i, \bar{e}_{-i})) - C_i(a_i(\bar{e}_i)) \qquad i = 1, 2 \quad (3.3)$$

$$\text{where} \quad A(\bar{e}_i, \bar{e}_{-i}) := \sum_i a_i(\bar{e}_i) \quad \text{and} \quad a_i(\bar{e}_i) := e_{i,0} - \bar{e}_i$$

Lemma 3.2

For each country $i \in \{1, 2\}$, there exists a unique Nash equilibrium cap $0 \leq \bar{e}_i^N < e_{i,0}$ that solves Problem (3.3). The first inequality is strict for at least one country.

Comparison of the Benchmarks

Proposition: National Caps Versus Social Planner

Compared to a social planner, national caps implement a strictly higher overall cap, $\sum_i \bar{e}_i^N > \bar{E}^S$, that leads to a strictly lower level of welfare, $W^N < W^S$.

- **Intuition:** Each country *i* has an incentive to free-ride on the abatement carried out by the other country, while implementing insufficient domestic abatement targets

Example I

Consider benefits that are captured by a benefit function of the form

$$B_i(A) = \beta_i(2\sqrt{A} - A)$$

where $\beta_i > 2\zeta_i\zeta_{-i}^2$ and $A \in [0, 1]$.

Even for the symmetric case where

- $e_{1,0} = e_{2,0} = 0.5$
- $\zeta_1 = \zeta_2 = 0.5$
- $\beta_1 = \beta_2 = 0.3$

free-riding leads to emissions that are about **35% above** the socially optimal emissions cap.

Part 4: Negotiations on the Emissions Cap

Negotiations on the Emissions Cap

- How would the countries **endogenously design** the cap-and-trade system?
- Natural approach: **Negotiations**
  - Start with the simplest form of negotiations: Countries negotiate **solely** on the overall emissions cap
  - Countries have already...
    - (i) **agreed on setting up a joint cap-and-trade system**
      e.g. due to the commitment to this political goal or public pressure
    - (ii) **determined a certain initial allocation of permits $\hat{\mu}_1 \in [0, 1]$**
      e.g. by preceding negotiations or according to current emissions
- However, (i) and (ii) will be dropped later

Pareto-Efficient Caps (I)

- Bargaining must result in a **Pareto-efficient** outcome
- To construct the **set of Pareto-efficient caps** $\mathscr{P}_{\hat{\mu}_1}$, we determine the cap $\bar{E}_i$ most preferred by country i
- Formally, $\bar{E}_i$ solves

$$\max_{0 \leq \bar{E} \leq E_0} W_i(\bar{E}, \hat{\mu}_1) \qquad i = 1, 2 \quad (4.1)$$

Lemma 4.1

For each country $i \in \{1, 2\}$, there exists a unique individually optimal cap $0 \leq \bar{E}_i < E_0$ that solves Problem (4.1). The first inequality is strict for at least one country. Moreover, it holds that $\min\{\bar{E}_1, \bar{E}_2\} \leq \bar{E}^S \leq \max\{\bar{E}_1, \bar{E}_2\}$.

Pareto-Efficient Caps (II)

Definition: Pareto-Efficient Caps

The set of Pareto-efficient caps, $\mathscr{P}_{\hat{\mu}_1} \subset \mathbb{R}_+$, is defined by

$$\mathscr{P}_{\hat{\mu}_1} := \left\{ \bar{E} : \bar{E} \in \left[\min\{\bar{E}_1, \bar{E}_2\}, \max\{\bar{E}_1, \bar{E}_2\} \right] \right\}.$$

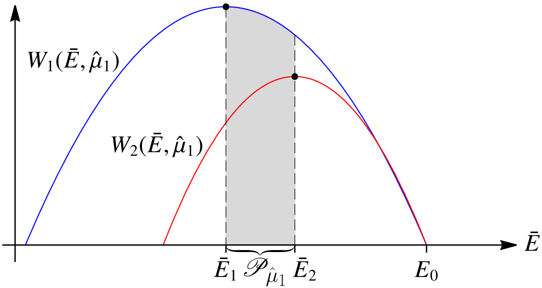

Figure: Individually optimal caps and pareto set $\mathscr{P}_{\hat{\mu}_1}$

Bargaining Procedure

- Most intuitive way to model a cap negotiation: According to Rubinstein's (1982) alternating-offers model
  1. Country i proposes a cap
  2. Country $-i$ can...
     - **(i)** Accept this offer and the game ends
     - **(ii)** Reject the offer and make a counteroffer after $\Delta > 0$ time units
  3. In case of a counteroffer, i decides whether **(i)** or **(ii)**
  4. ...
- SPE in this game converges to Nash's (1950) bargaining solution if $\Delta \to 0$ (Binmore, Rubinstein & Wolinsky, 1986; Binmore, 1987)
  - **Justified in our setup**: Bargaining process is substantially faster than climate change

Bargaining Solution (I)

- Nash bargaining solution $\bar{E}^B$ is defined as solution to:

$$\max_{\bar{E}} \mathcal{N}_{\hat{\mu}_1}(\bar{E}) := W_1(\bar{E}, \hat{\mu}_1) \cdot W_2(\bar{E}, \hat{\mu}_1) \qquad \text{s.t. } \bar{E} \in \mathscr{P}_{\hat{\mu}_1} \tag{4.2}$$

- The FOC corresponding to (4.2) reads

$$\frac{\mathrm{d}\,\mathcal{N}_{\hat{\mu}_1}(\bar{E})}{\mathrm{d}\bar{E}} = \sum_i \frac{\mathrm{d}W_i(\bar{E}, \hat{\mu}_1)}{\mathrm{d}\bar{E}} \cdot W_{-i}(\bar{E}, \hat{\mu}_1) = 0. \tag{4.3}$$

Lemma 4.3

There exists a unique Nash bargaining solution $0 \leq \bar{E}^B < E_0$ that solves Problem (4.2). Any $\bar{E}^B > 0$ is determined by the unique solution to (4.3) in $\mathscr{P}_{\hat{\mu}_1}$.

Bargaining Solution (II)

Proposition: Bargaining over the Emissions Cap

Consider two countries that agreed upon setting up a joint cap-and-trade system with an initial allocation $\hat{\mu}_1$ and bargain over the amount of permits. Then the following holds:

(i) If the countries are sufficiently symmetric in terms of benefits, costs, and initial emissions, then there exists a unique initial allocation $\mu_1^S \in [0, 1]$ for which $\bar{E}^B = \bar{E}^S$.

(ii) If, by contrast, $B_i(A(\bar{E}^S)) - B_{-i}(A(\bar{E}^S))$ sufficiently large, then $\bar{E}^B \neq \bar{E}^S$.

Bargaining Solution (III)

(i) For sufficiently symmetric countries: Negotiating the emissions cap **may be** welfare-improving compared to national caps

- The allocation μ_1^S eliminates efficiency-fairness trade-off in bargaining
- If the countries initially agreed on $\hat{\mu}_1$ sufficiently close to $\mu_1^S \in [0, 1]$, then $W^S \geq W(\bar{E}^B) > W^N$

$\Longrightarrow$ Negotiations **may** overcome/alleviate the **incentive to free-ride**

(ii) Allocation of permits constitutes an **implicit side payment** (Buchholz, Haupt & Peters, 2005; Caparrós, 2016)

- Scope for providing side payments is **limited**
- If benefits are too different, then side payments are **insufficient** for the low-benefit country to agree on the socially optimal cap ($\mu_1^S \notin [0, 1]$)

Example II

Revisit the symmetric parameterization of Example I and vary β_2

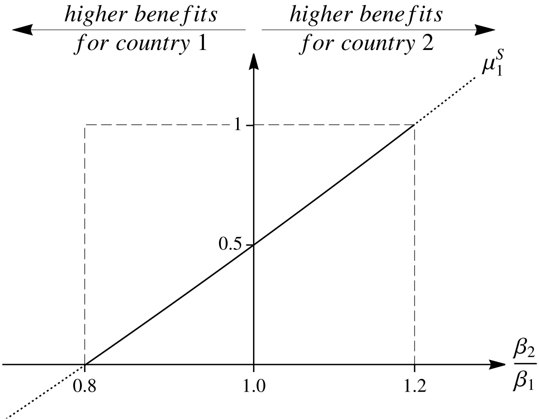

Figure: Optimal initial allocation ($e_{1,0} = e_{2,0} = 0.5$, $\zeta_1 = \zeta_2 = 0.5$, $\beta_1 = 0.3$)

Part 5: Negotiations on Emissions Cap & Allocation of Permits

Negotiations on Emissions Cap & Allocation

- Add a further degree of freedom: Countries negotiate **simultaneously** on the **emissions cap** and the **permit allocation**
  - Offer in the alternating-offers model now consists of a tuple $(\bar{E}, \mu)$

Definition: Pareto-Efficient Tuples

The set of Pareto-efficient tuples, $\mathscr{P} \subset \mathbb{R}_+ \times [0,1]$, is the set of all tuples $(\bar{E}, \mu_1)$ for which no other tuple $(\bar{E}', \mu_1')$ exists that satisfies

$$W_i(\bar{E}', \mu_1') \geq W_i(\bar{E}, \mu_1), \quad \text{and} \quad W_{-i}(\bar{E}', \mu_1') > W_{-i}(\bar{E}, \mu_1)$$

for at least one $i \in \{1, 2\}$, where $\mu_1, \mu_1' \in [0, 1]$.

Bargaining Solution (I)

- The bargaining solution $(\bar{E}^B, \mu^B)$ is defined by a solution to

$$\max_{(\bar{E},\mu_1)} \mathcal{N}(\bar{E}, \mu_1) := W_1(\bar{E}, \mu_1) \cdot W_2(\bar{E}, \mu_1) \qquad \text{s.t. } (\bar{E}, \mu_1) \in \mathscr{P}.$$

Proposition: Bargaining over the Emissions Cap & Allocation

Consider two countries that agreed upon setting up a joint cap-and-trade system and bargain over the amount and allocation of permits. Then the following holds:

(i) If the countries are sufficiently symmetric in terms of benefits, costs, and initial emissions, then $\bar{E}^B = \bar{E}^S$ and $\mu_1^B = \mu_1^S$.

(ii) If, by contrast, $B_i(A(\bar{E}^S)) - B_{-i}(A(\bar{E}^S))$ sufficiently large, then $\bar{E}^B \neq \bar{E}^S$.

Bargaining Solution (II)

(i) For sufficiently symmetric countries, bargaining **maximizes welfare**

- Countries agree on a cap that yields the **highest level of welfare**
- Welfare is distributed **equally** via the allocation of permits
- Allowing the countries to negotiate on the amount and allocation of permits completely **removes the distortions** created by the free-riding incentive

(ii) Allocation of permits constitutes an **implicit side payment** (Buchholz, Haupt & Peters, 2005; Caparrós, 2016)

- If benefits are too different, then side payments are **insufficient** for the low-benefit country to agree on the socially optimal cap
- Holds true **irrespective** of whether the allocation of permits is **exogenously** given or **endogenously** determined

Comparison with the Coase Theorem

- Exhausted scope for side payments in **(ii)** can be interpreted as **infinite transaction costs**
  - Coase Theorem does not apply
- Is **(i)** a mere consequence of the Coase Theorem?
  – **No, because...**
  1. Formal bargaining models will **not generally result in the efficient outcome** predicted by the rather informal Coase Theorem (Hahnel & Sheeran, 2009)
  2. Property rights in our setup are **ex ante not well defined** (exact purpose of the negotiation is to determine these rights)

Modifying the Bargaining Procedure

- Rubinstein's (1982) alternating-offers model with strategic termination
  1. Country i proposes a cap
  2. Country $-i$ can ...
     - (i) Accept this offer and the game ends
     - (ii) Reject the offer and make a counteroffer after $\Delta > 0$ time units
     - (iii) **Strategically opt out and both countries obtain their outside option**
  3. In case of a counteroffer, i decides whether **(i)**,**(ii)**, or **(iii)**
  4. ...
- Countries must rely on **national caps** in case setting up a joint cap-and-trade system fails
  - Country i's outside option is W_i^N

Bargaining Solution

- Following Binmore (1985); Binmore, Rubinstein & Wolinsky, (1986), and Muthoo (1999), the SPE in the extended alternating-offers model converges to the solution to

$$\max_{\bar{E},\mu_1} \mathcal{N}(\bar{E},\mu_1) = W_1(\bar{E},\mu_1) \cdot W_2(\bar{E},\mu_1)$$

$$\text{s.t.} \quad (\bar{E},\mu_1) \in \mathscr{P}, \quad W_1(\bar{E},\mu_1) \geq W_1^N, \quad W_2(\bar{E},\mu_1) \geq W_2^N.$$

Proposition: Bargaining with Outside Option

Consider two countries that bargain on setting up a joint cap-and-trade system. If the countries are sufficiently symmetric in terms of benefits, costs and initial emissions, then they agree on setting up a joint cap-and-trade system with $\bar{E}^B = \bar{E}^S$ and $\mu_1^B = \mu_1^S$.

Example III

Revisit the symmetric parameterization of Example I, where $\beta_1 = 0.3$.

(i) For $\beta_2/\beta_1 \in [0.8, 0.97)$ bargaining implements $\bar{E}^S$, while μ_1 is determined by providing a welfare level to country 1 that equals its outside option.

(ii) For $\beta_2/\beta_1 \in [0.97, 1.03]$ bargaining implements $\bar{E}^S$ and μ_1 is determined by equalizing the corresponding welfare levels in both countries.

(iii) For $\beta_2/\beta_1 \in (1.03, 2.05]$ bargaining implements $\bar{E}^S$, while μ_1 is determined by providing a welfare level to country 2 that equals its outside option.

(iv) By contrast, for $\beta_2/\beta_1 > 2.05$ bargaining does not implement $\bar{E}^S$.

Part 6: Multilateral Negotiations

Multilateral Negotiations Without Outside Option

- Bargaining implements the efficient cap if and only if a **feasible** allocation of permits exists that **equates welfare levels** in all countries resulting from the efficient cap
- **Feasible** allocation:

$$\sum_i \mu_i = 1, \qquad \text{and} \qquad \mu_i \in [0,1], \qquad i = 1, \ldots, n.$$

  - **Symmetric case:** $\mu_i = 1/n$ constitutes the unique **feasible** allocation that equates welfare levels from the efficient cap
  - **Asymmetric case:** If $B_i(A(\bar{E}^S)) - B_j(A(\bar{E}^S))$ is sufficiently large for at least two countries i and j, then equating welfare levels either requires $\mu_i < 0$ or $\mu_j > 1$, which is **not feasible**.

$\Longrightarrow$ **Results generalize** to the case of $n > 2$ countries

Multilateral Negotiations With Outside Option

- In the symmetric case, it also holds that

$$W_i(\bar{E}^S, 1/n) = \frac{W^S}{n} > \frac{W^N}{n} = W_i^N, \qquad i = 1, \dots, n.$$

- If all $n > 2$ countries are **sufficiently symmetric**, they will set up a cap-and-trade system with an **efficient emissions cap**

$\Longrightarrow$ **Results generalize** to the case of $n > 2$ countries

Part 7: Conclusion

Key Results & Implications

- Propose a **simple mechanism** to circumvent the inefficiency caused by the free-riding incentive
  - Enabling countries to **set up joint cap-and-trade systems** and allowing them to **negotiate** the **cap** and **allocation** of permits
  - Maximizes welfare if the countries are **sufficiently symmetric**
- Discover why this mechanism may not implement efficient outcomes
  - Insufficient scope for implicit side payments if countries are **too heterogeneous**
- Negotiations are useful in **designing cap-and-trade systems**
- It is crucial to **remove all sorts of barriers** that
  - (i) hinder countries from setting up a joint cap-and-trade system
  - (ii) prevent them from linking existing schemes

Part 8: References

References (I)

- Barrett, S. (1994). Self-enforcing international environmental agreements. *Oxford Economic Papers, 46* (Supplement 1), 878–894.
- Binmore, K. (1985). Bargaining and coalitions. In A. Roth (Ed.), *Game-theoretic models of bargaining* (p. 269-–304). Cambridge, UK: Cambridge University Press.
- Binmore, K. (1987). Nash bargaining theory ii. In K. Binmore & P. Dasgupta (Eds.), *The economics of bargaining* (pp. 61–76). Oxford: Blackwell.
- Binmore, K., Rubinstein, A., & Wolinsky, A. (1986). The nash bargaining solution in economic modelling. *RAND Journal of Economics, 17* (2), 176–188.
- Buchholz, W., Haupt, A., & Peters, W. (2005). International environmental agreements and strategic voting. *Scandinavian Journal of Economics, 107* (1), 175–195.
- Caparrós, A. (2016). Bargaining and international environmental agreements. *Environmental and Resource Economics, 65* (1), 5–31.
- Gersbach, H., & Hummel, N. (2016). A development-compatible refunding scheme for a climate treaty. *Resource and Energy Economics, 44* , 139–168.

References (II)

- Hahnel, R., & Sheeran, K. A. (2009). Misinterpreting the coase theorem. *Journal of Economic Issues, 43* (1), 215–238.
- McGinty, M. (2007). International environmental agreements among asymmetric nations. *Oxford Economic Papers, 59* (1), 45–62.
- Muthoo, A. (1999). *Bargaining theory with applications.* Cambridge, UK: Cambridge University Press.
- Nash, J. F. (1950). The bargaining problem. *Econometrica, 18* (2), 155–162.
- Rubinstein, A. (1982). Perfect equilibrium in a bargaining model. *Econometrica, 50* (1), 97–109.
- Stern, N. H. (2008). The economics of climate change. *American Economic Review: Papers & Proceedings, 98* (2), 1–37.
- Weitzman, M. L. (1974). Prices vs. quantities. *Review of Economic Studies, 41* (4), 477–491.
- Weitzman, M. L. (2014). Can negotiating a uniform carbon price help to internalize the global warming externality? *Journal of the Association of Environmental and Resource Economists, 1* (1/2), 29–49.