Win as a Team or Fail as Individuals

Cooperation and Non-Cooperation in the Climate Tax Game

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The Climate Problem

- Large and growing literature on economics of climate change.
- *Dynamic general equilibrium theory* to study optimal climate policies:
  - Golosov et al. (2014, ECMA)
  - Hambel, Kraft & Schwartz (2021, JIE)
  - Hillebrand & Hillebrand (2019, JET).
- *Game theory* to study cooperation and non-cooperation:
  - Battaglini & Harstad (2016, JPE)
  - Harstad (2012, ReStud)
  - Harstad (2012, JEEA).
- This paper:
  - *dynamic general equilibrium* model of climate change
  - multiple heterogeneous countries, trade
  - optimal climate policies under *cooperation* and *non-cooperation*
  - transfer polices inducing full cooperation of countries.

This Talk

1. The Model
2. Climate Policy and Equilibrium
3. Optimal Climate Policy under
    I. non-cooperation
    II. full cooperation
    III. partial cooperation (coalitions).
4. Optimal Transfers
5. Extensions

1. The Model

Model setup

- Discrete time $t = 0, 1, 2, \ldots$
- $L \geq 2$ countries/regions, set of players $\mathbb{L} := \{1, \ldots, L\}$.
- Building blocks of the model:
  A. Production sectors:
    A.1 final sector
    A.2 resource sector.
  B. Climate model
  C. Consumption sector
  D. Markets and trade.

Stage A.1: Final production in region ℓ

- Final sector in region $\ell \in \mathbb{L}$:
  - gross production function $F_t^\ell : \mathbb{R}_+^2 \longrightarrow \mathbb{R}_+$ determining final output

$$Y_t^\ell = \underbrace{(1 - D^\ell(S_t))}_{\text{climate damage}} F_t^\ell(K_t^\ell, X_t^\ell).$$

  - capital K_t^ℓ and fossil energy X_t^ℓ as inputs
  - standard restrictions (C^2, concavity, monotonicity) on F_t^ℓ
  - time-dependence allows for various sources of exogenous growth
  - *climate damage* depending on climate state S_t.
- Climate damage function $D^\ell : \mathbb{R}_+ \longrightarrow [0,1]$

$$D^\ell(S_t) := 1 - \exp\left(-\gamma^\ell S_t\right).$$

Marginal climate damage will be $\gamma^\ell Y_t^\ell$.

Stage A.2: Resource extraction in region ℓ

- Resource sector extracts fossil fuels (oil, coal, gas):
  - given initial stock $R_0^\ell \geq 0$
  - constant extraction cost $c_x > 0$ per unit
  - extraction path $(X_t^{\ell,s})_{t\geq 0}$ satisfies feasibility constraint:

$$\sum_{t=0}^{\infty} X_t^{\ell,s} \leq R_0^\ell.$$

- World resource supply in period t:

$$\overline{X}_t^s := \sum_{\ell \in \mathbb{L}} X_t^{\ell,s}.$$

B. Climate model

- Global emissions from burning fossil fuels in final production:

$$\overline{X}_t := \sum_{\ell \in \mathbb{L}} X_t^\ell.$$

- Climate state S_t represents total atmospheric CO_2 concentration:

$$S_t = \sum_{n=0}^{\infty} \delta_n \overline{X}_{t-n}$$

$\delta_n \geq 0$: share of emissions left in atmosphere after n periods.

- Historical emissions $(\overline{X}_{-t})_{t \geq 1}$ before $t = 0$ are given.
- Specification includes Golosov et al. (2014), Gerlagh & Liski (2018).

C. Consumption sector in region ℓ

- Representative consumer:
  - income from capital, profits, lump-sum transfers
  - decision on $(C_t^\ell, K_{t+1}^{\ell,s})_{t\geq 0}$
  - time-additive preferences over lifetime consumption:

$$U((C_t^\ell)_{t\geq 0}) = \sum_{t=0}^{\infty} \beta^t u(C_t^\ell), \quad 0 < \beta < 1.$$

  - period utility consistent w/ balanced growth (King et al.(1988)):

$$u(C) = \begin{cases} \frac{C^{1-\sigma}-1}{1-\sigma} & \text{for } \sigma > 0, \sigma \neq 1 \\ \log C & \text{for } \sigma = 1. \end{cases} \tag{1}$$

- Aggregate consumption and capital formation is

$$\overline{C}_t := \sum_{\ell\in\mathbb{L}} C_t^\ell \quad \text{and} \quad \overline{K}_{t+1}^s := \sum_{\ell\in\mathbb{L}} K_{t+1}^{\ell,s}.$$

D. Markets and trade

- International markets for
  - capital:

$$\sum_{\ell \in \mathbb{L}} K_t^\ell = \overline{K}_t^s \qquad \rightsquigarrow r_t$$

  - exhaustible resources:

$$\sum_{\ell \in \mathbb{L}} X_t^\ell = \overline{X}_t^s \qquad \rightsquigarrow v_t.$$

  - consumption good (numeraire):

$$\sum_{\ell \in \mathbb{L}} Y_t^\ell = \sum_{\ell \in \mathbb{L}} C_t^\ell + \sum_{\ell \in \mathbb{L}} K_{t+1}^\ell + c_x \sum_{\ell \in \mathbb{L}} X_t^\ell.$$

- Frictionless markets, intertemporal borrowing and lending.

2. Climate Policy and Equilibrium

Climate policy

- Climate policy chosen by region $\ell \in \mathbb{L}$:
  - emissions taxes $(\tau_t^\ell)_{t\geq 0}$
  - lump-sum transfers $(T_t^\ell)_{t\geq 0}$.
- Tax τ_t^ℓ paid by final sector per unit of fossil energy X_t^ℓ.
- Feasible transfers under cooperation and non-cooperation:
  - non-cooperation:

$$T_t^\ell = \underbrace{\tau_t^\ell X_t^\ell}_{\text{regional tax revenue}} . \tag{2}$$

  - full cooperation:

$$T_t^\ell = \theta^\ell \cdot \underbrace{\sum_{k\in\mathbb{L}} \tau_t^k X_t^k}_{\text{global tax revenue}} . \tag{3}$$

Transfer policy $(\theta^\ell)_{\ell\in\mathbb{L}}$ satisfies $\sum_{\ell\in\mathbb{L}} \theta^\ell = 1$.

Equilibrium

Definition

A decentralized equilibrium consists of a feasible climate policy $(\tau_t^\ell, T_t^\ell)_{t\geq 0}$ for each region $\ell \in \mathbb{L}$, an allocation

$$A^* = ((K_t^{\ell *}, X_t^{\ell *}, C_t^{\ell *})_{\ell \in \mathbb{L}})_{t\geq 0},$$

and a price system

$$P^* = (r_t^*, v_t^*)_{t\geq 0}$$

consistent with *market clearing*, *optimal behavior* of consumers and all producers, the exhaustible *resource constraint*, and the *climate model*.

Lemma

The equilibrium consumption distribution $\mu = (\mu^\ell)_{\ell \in \mathbb{L}}$ *is constant:*

$$C_t^\ell = \mu^\ell \overline{C}_t \quad \textit{for all} \quad t = 0, 1, 2, \ldots$$

3. Optimal Climate Policy

Case I: Non-cooperation

- All players $\ell \in \mathbb{L}$:
  - choose regional taxes $(\tau_t^{\ell,\mathrm{nc}})_{t\geq 0}$ to maximize *domestic utility*
  - take as given in their decision:
    - aggregate emissions $(\overline{X}_t^{-\ell})_{t\geq 0}$ of all other regions
    - international prices $(r_t, v_t)_{t\geq 0}$.
  - transfer entire tax revenue to domestic consumers.

Theorem

The non-cooperative tax policy $(\tau_t^{\ell,\mathrm{nc}})_{t\geq 0}$ is determined by the rule

$$\tau_t^{\ell,\mathrm{nc}} = \sum_{n=0}^{\infty} \beta^n \left(\overline{C}_{t+n}/\overline{C}_t\right)^{-\sigma} \times \delta_n \times \gamma^\ell Y_{t+n}^\ell.$$

*and is the sum of all discounted future **domestic** climate damages.*

Case II: Full cooperation

- All countries coordinate on a globally optimal climate policy
- Optimal policy maximizes utility of a world representative consumer.

Theorem

The optimal climate tax policy is uniform across countries and of the form

$$\tau_t^{\ell,\text{opt}} \equiv \tau_t^{\text{opt}} := \sum_{n=0}^{\infty} \beta^n \left(\overline{C}_{t+n}/\overline{C}_t\right)^{-\sigma} \times \delta_n \times \sum_{k \in \mathbb{L}} \gamma^k Y_{t+n}^k.$$

*and is the sum of all discounted future **global** climate damages.*

- Compare this to the non-cooperative tax policy

$$\tau_t^{\ell,\text{nc}} = \sum_{n=0}^{\infty} \beta^n \left(\overline{C}_{t+n}/\overline{C}_t\right)^{-\sigma} \times \delta_n \times \gamma^\ell Y_{t+n}^\ell.$$

which internalizes *only domestic damages*!

Case III: Partial cooperation/coalition formation

- Each region $\ell \in \mathbb{L}$ joins some coalition $\mathbb{L}' \subset \mathbb{L}$.
- Coalition structure $\mathscr{L}$ is a partition of $\mathbb{L}$ into $N \geq 1$ coalitions:

$$\mathscr{L} = \left\{\mathbb{L}_1, \ldots, \mathbb{L}_N\right\}, \quad \bigcup_{n=1}^{N} \mathbb{L}_n = \mathbb{L}. \tag{4}$$

- Each coalition maximizes aggregate utility of its members.

Theorem

The optimal tax chosen by each coalition member $\ell \in \mathbb{L}' \in \mathscr{L}$ is

$$\tau_t^\ell = \tau_t^{\mathbb{L}',\mathrm{opt}} := \sum_{n=0}^{\infty} \beta^n \left(\overline{C}_{t+n} / \overline{C}_t\right)^{-\sigma} \times \delta_n \times \sum_{k \in \mathbb{L}'} \gamma^k Y_{t+n}^k.$$

Corollary: The grand coalition $\mathbb{L}' = \mathbb{L}$ chooses $\tau_t^{\mathbb{L}',\mathrm{opt}} = \tau_t^{\mathrm{opt}}$!

4. Optimal Transfers

Transfer policies

- Regions choose transfer policy $\theta = (\theta^\ell)_{\ell \in \mathbb{L}}$ to redistribute tax revenue.
- Regional consumption $(C_t^{\ell,\mathrm{nc}})_{t \geq 0}$ under non-cooperation.
- Aggregate consumption $(\overline{C}_t^{\mathrm{opt}})_{t \geq 0}$ under full-cooperation

Lemma

For each $\ell \in \mathbb{L}$, the following holds:

(i) *There exists a minimal consumption share $\mu_{\min}^\ell \geq 0$ such that*

$$U\Big((\mu_{\min}^\ell \times \overline{C}_t^{\mathrm{opt}})_{t \geq 0}\Big) = U\Big(\big(C_t^{\ell,\mathrm{nc}}\big)_{t \geq 0}\Big). \quad (5)$$

(ii) *There exists a critical transfer share $\theta_{\min}^\ell > 0$ such that*

$$\theta^\ell \geq \theta_{\min}^\ell \quad \Longrightarrow \quad \mu^\ell \geq \mu_{\min}^\ell .$$

The critical transfer shares satisfy $\sum_{\ell \in \mathbb{L}} \theta_{\min}^\ell < 1$.

Optimal transfer policies

Theorem

Any transfer policy $\theta = (\theta^\ell)_{\ell \in \mathbb{L}}$ *which satisfies*

$$\theta^\ell \geq \theta^\ell_{\min} \quad \textit{for all} \quad \ell \in \mathbb{L}$$

makes each $\ell \in \mathbb{L}$ *better-off under cooperation relative to non-cooperation.*

Extensions

- Aggregate shocks and uncertainty
- Trade frictions
- Process of coalition formation
- ...

Thank you very much for your attention!