Post-Kyoto Climate Negotiations: A Dynamic Game Approach

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1. **Games and IAMs**
   - The post-Kyoto negotiation framework
     - The game model
     - The normalized equilibrium concept
     - CGE modeling

2. **Oracle based optimization**
   - OBO
   - Analytic Center Cutting Plane Method

3. **Some experiments**
   - Scenario
   - Preliminary results

4. **Conclusion**
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Equilibrium in CBA

- Carbone J.C., Rutherford T. and Helm C., Coalition formation and international trade in greenhouse gas emissions, mimeo, 2003.
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Can we apply the equilibrium concept in a cost-effectiveness approach?
Use the concept of *equilibrium with coupled constraints*.


Use the concept of *equilibrium with coupled constraints*.


Equilibrium in CEA

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The context...

**Storyline**

- All nations share a responsibility in the global warming due to GHG concentration.
- In a post Kyoto negotiation run, all countries will have to decide abatement policies.
- A mixture of cooperative (attainment of a common goal) and non-cooperative (economic selfishness) behavior is represented in a dynamic game with coupled constraints.

"I'm starting to get concerned about global warming."
We consider two time periods: (t=0) 2000-2025 and (t=1) 2025-2050.

Players are collectively committed (forced?) to reach a target on total cumulative emissions by the year 2050.

We denote $\bar{e}_j(t)$ the cap decided by player $j$ for period $t$, and $\bar{E}$ is the global constraint. The following equality must be satisfied

$$h(\bar{e}) = \sum_{j \in M} \sum_{t=0}^{1} \bar{e}_j(t) - \bar{E} \leq 0 \quad (1)$$
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$$h(\bar{e}) = \sum_{j \in M} \sum_{t=0}^{1} \bar{e}_j(t) - \bar{E} \leq 0$$  \hspace{1cm} (1)
The result of a global $m$-country economic equilibrium defines a welfare gain for each player at $t$ which is denoted $W_{j,t}(\bar{e}(t))$.

Given an emission program $\bar{e} = \{\bar{e}(t)\mid t = 0, 1\}$ the total payoff to player $j$ is given by

$$J_j(\bar{e}) = \sum_{t=0}^{1} W_{j,t}(\bar{e}(t)) \quad j \in M. \quad (2)$$
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Definition

Let us call $\mathcal{E}$ the set of emissions $\bar{e}$ that satisfy the constraints (1). Denote also $[\bar{e}^{*j}, \bar{e}_j]$ the emission program obtained from $\bar{e}^*$ by replacing only the emission program $\bar{e}_j^*$ of player $j$ by $\bar{e}_j$. The emission program $\bar{e}^*$ is an equilibrium under the coupled constraints (1) if the following holds for each player $j \in M$

\begin{align*}
\bar{e}^* & \in \mathcal{E} \quad (3) \\
J_j(\bar{e}^*) & \geq J_j([\bar{e}^{*j}, \bar{e}_j]) \quad \forall \bar{e}_j \text{ s.t. } [\bar{e}^{*j}, \bar{e}_j] \in \mathcal{E}. \quad (4)
\end{align*}

In this equilibrium, each player replies optimally to the emission program chosen by the other players, under the constraint that the global cumulative emission limits must be respected.
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Rosen (1965) has proposed the concept of *normalized equilibrium* when the *coupled constraint* satisfy the usual “qualification conditions”.

The players share a common Kuhn-Tucker multiplier satisfying $\lambda^0 \geq 0$ with $\lambda^0 h(\bar{e}^*) = 0$. They play a game where the payoff to player $i$ is

$$L_i(\bar{e}, \lambda^0) = J_i(\bar{e}) - \frac{\lambda^0}{r_i}(h(\bar{e}))$$

(5)

The K-T multiplier is such that at the Nash-equilibrium for the payoffs (5) the constraint is satisfied.
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Normalized equilibrium

Each player has a positive weight $r_i$. The weights sum to one.

The higher the weight $r_i$ the lower the share of the burden.

For each weighting the equilibrium exists and is unique under strict diagonal concavity conditions.

The equilibrium is the solution of a variational inequality problem.
The case of linear models

Assume each country is described by a linear model

\[
\begin{align*}
\min & \quad c_j x_j \\
A_j x_j & = \quad b_j \\
D_j x_j & \geq \quad d_j \\
E_j x_j & = \quad e_j
\end{align*}
\]

We look for an equilibrium under the coupled constraint

\[
\sum_{j=1,\ldots,m} e_j \leq \bar{e}.
\]
The fixed point condition that characterizes a normalized equilibrium is equivalent to the optimization of the scalarized criterion

\[
\sum_{j=1,\ldots,m} r_j c_j x_j \tag{11}
\]

s.t.

\[
A_j x_j = b_j \quad j = 1, \ldots, m \tag{12}
\]
\[
D_j x_j \geq d_j \quad j = 1, \ldots, m \tag{13}
\]
\[
E_j x_j = e_j \quad j = 1, \ldots, m \tag{14}
\]
\[
\sum_{j=1,\ldots,m} e_j \leq \bar{e}. \tag{15}
\]

In this case, the normalized equilibrium is also Pareto.
Linear models do not capture the essential effects of international trade (in commodities and emission permits).
For that we need to go through a more encompassing CGE modeling approach.
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Aggregate version of GEMINI-E3:

- CGE model in 3 regions and 14 sectors
- Based on GTAP-5 database
- Non-CO2 gases (EMF21 data)
Payoffs from a CGE model

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GEMINI is the oracle

- Given quotas for each period and region GEMINI tells what the welfare gains are.
- Through sensitivity analysis it can also give an indication of what the "pseudogradient" is.
- This information can be used in an Oracle Based Optimization (OBO) method to solve the variational inequality.
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Coupling ACCPM with GEMINI

ACCPM proposes a quotas allocation which is at the center of a localization set.

GEMINI-E3 returns welfare values and sensitivity (sub-gradient) vectors.

With this new information the localization set shrinks and ACCPM proposes new quotas at the analytic center of the localization set.

The procedure continues until the localization set is very small.
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Stabilization scenario

- Stabilization toward 550 ppmv
- A target on total cumulative emissions by 2050
- 3 players: USA, other-OECD (IND), and developing countries (SUD)
- 2 periods of 25 years each
- Global emission trading
Stabilization scenario

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Global carbon emissions

Stabilization toward 550 ppmv means convergence level of 4.5 tC-eq/cap in 2050 (RIVM report):

- 11 GtC-eq in 2050,
- -30% of global GHG emissions by 2050,
- Global quota is around 480 GtC-eq.
Global carbon emissions

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Global carbon price

- ≃ 108 $/tC in 2025,
- ≃ 160 $/tC in 2050.
Global carbon price

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Burden sharing

- Same weight for everybody,
- USA = -33%, IND = -26%, SUD = -47%,
- Progressive reduction,
- Costly to delay.
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Discounted welfare costs, 2000-2050 (in billion USD)

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- Discounting = 3%,
- Same cost for US and OECD,
- Costly solution for DCs,
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Increase the weighting of the poorest

- USA and IND have the same weight,
- SUD has a zero cost if its weight is 0.515.
- -20% reduction is neutral for SUD.
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Varying the weights,
the higher the weight the lower the cost.
Discounted welfare costs, 2000-2050 (in billion USD)

Varying the weights, the higher the weight the lower the cost.
Nobody is better off (compared to the BaU),
- USA weight between 0.16 and 0.38,
- IND weight between 0.18 and 0.37,
- SUD weight between 0.24 and 0.53.
Acceptable weights

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Further research

- Link CGE and world MARKAL/TIMES models
- More regions, more periods...
- Test different weighting and burden sharing schemes (e.g. based on population, GDP, etc)
- Introduce the uncertainty on climate sensitivity (EMF22)
- Formulate a stochastic coupled game
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