Post-Kyoto Climate Negotiations: A Dynamic Game Approach

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M. Vielle   L. Viguier

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Outline

The context...

"I'm starting to get concerned about global warming."

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.

Game model

- 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

$$h(\bar{e}) = \sum_{j \in M} \sum_{t=0}^{1} \bar{e}_j(t) - \bar{E} \leq 0 \qquad (1)$$

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Game model

- 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* $\bar{e} = \{\bar{e}(t)| : t = 0, 1\}$ the total payoff to player j is given by

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

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Coupled equilibrium

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 $j \in M$

$$\bar{e}^* \in \mathcal{E} \tag{3}$$
$$J_j(\bar{e}^*) \geq J_j([\bar{e}^{*-j}, \bar{e}_j]) \quad \forall \bar{e}_j \text{ s.t. } [\bar{e}^{*-j}, \bar{e}_j] \in \mathcal{E}. \tag{4}$$

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.

Outline

Game model

- 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

$$L_i(\bar{e}, \lambda^0) = J_i(\bar{e}) - \frac{\lambda^0}{r_i}(h(\bar{e})) \tag{5}$$

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

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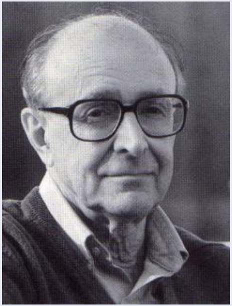
Normalized equilibrium

J.B. Rosen



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

$$\begin{aligned} \min \quad & c_j x_j && (6) \\ A_j x_j &= b_j && (7) \\ D_j x_j &\geq d_j && (8) \\ E_j x_j &= e_j && (9) \end{aligned}$$

We look for an equilibrium under the coupled constraint

$$\sum_{j=1,\dots,m} e_j \leq \bar{e}. \tag{10}$$

Proof of efficiency

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.

$$\begin{aligned} A_j x_j &= b_j \quad j = 1, \ldots m \quad (12) \\ D_j x_j &\geq d_j \quad j = 1, \ldots m \quad (13) \\ E_j x_j &= e_j \quad j = 1, \ldots m \quad (14) \\ \sum_{j=1,\ldots,m} e_j &\leq \bar{e}. \quad (15) \end{aligned}$$

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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Payoffs from a CGE model

Aggregate version of GEMINI-E3 :

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

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1. Games and IAMs
2. The post-Kyoto negotiation framework
   - The game model
   - The normalized equilibrium concept
   - CGE modeling
3. Oracle based optimization
   - OBO
   - Analytic Center Cutting Plane Method
4. Some experiments
   - Scenario
   - Preliminary results
5. Conclusion

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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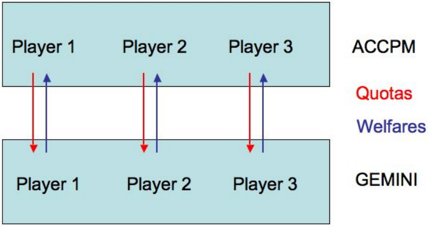
Coupling ACCPM with GEMINI



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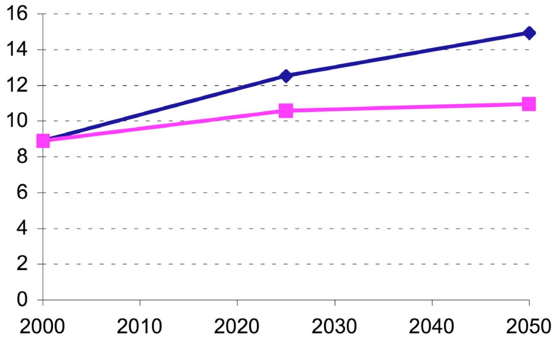
Stabilization toward 550 ppmv means convergence level of 4.5 tC-eq/cap in 2050 (RIVM report) :



Definition

1. 11 GtC-eq in 2050,
2. -30% of global GHG emissions by 2050,
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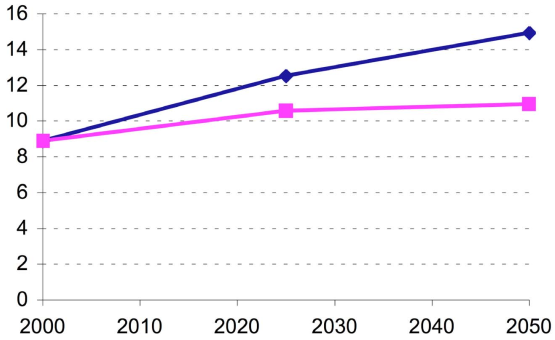

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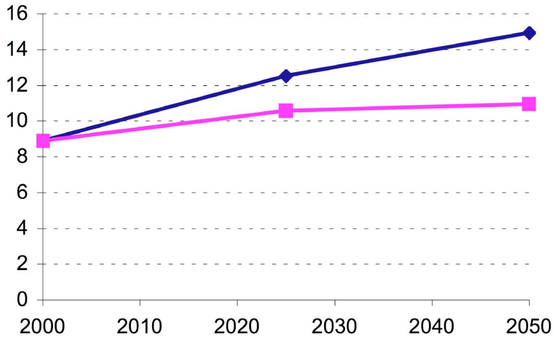

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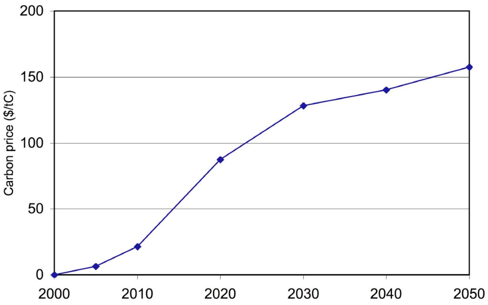

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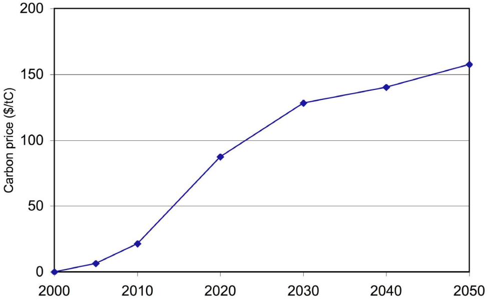

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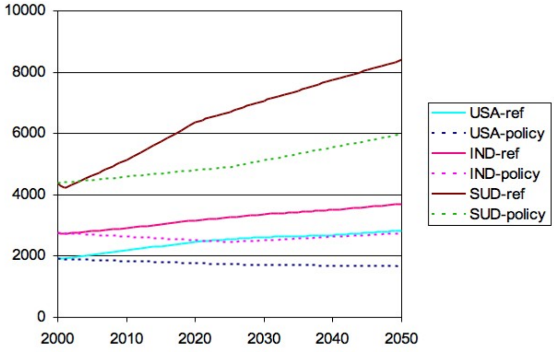
Burden sharing



- Same weight for everybody,
- USA=-33%, IND=-26%, SUD=-47%,
- Progressive reduction,
- Costly to delay.

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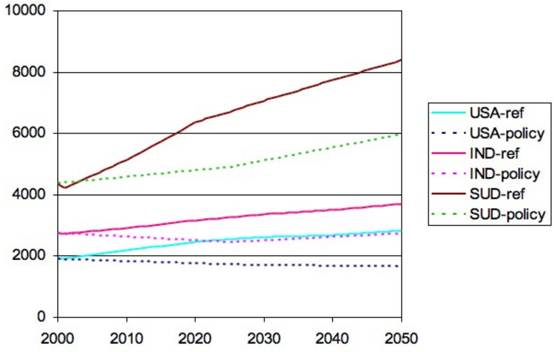

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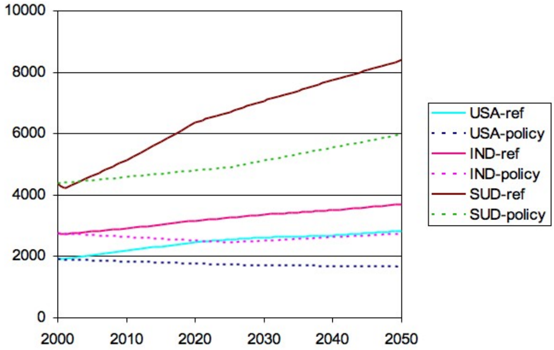

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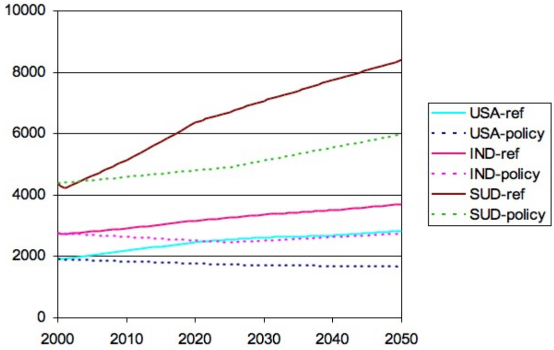

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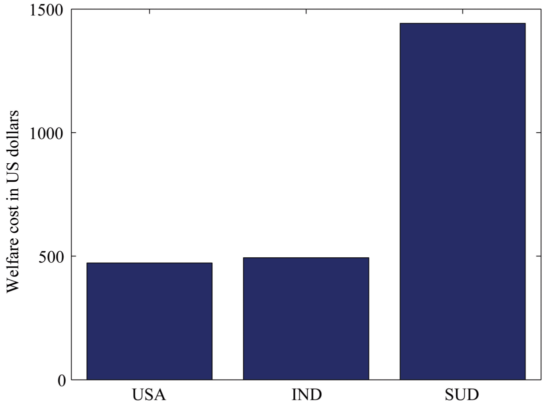

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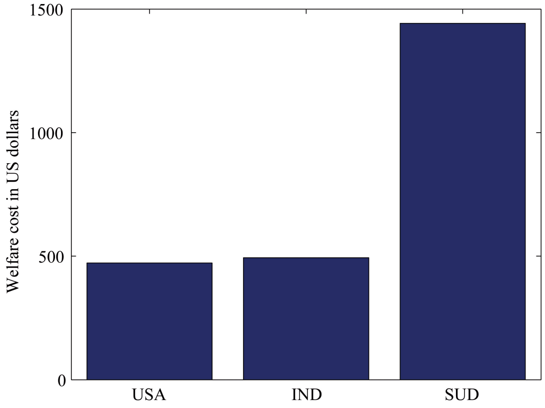

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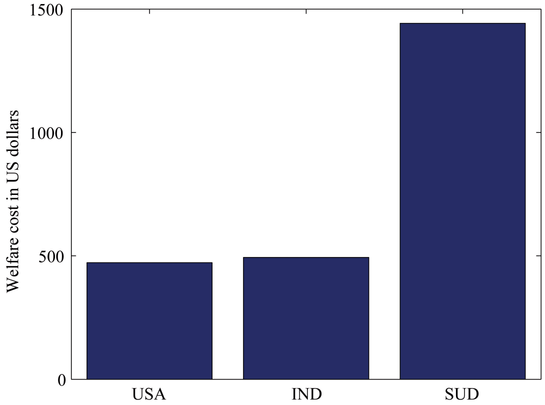

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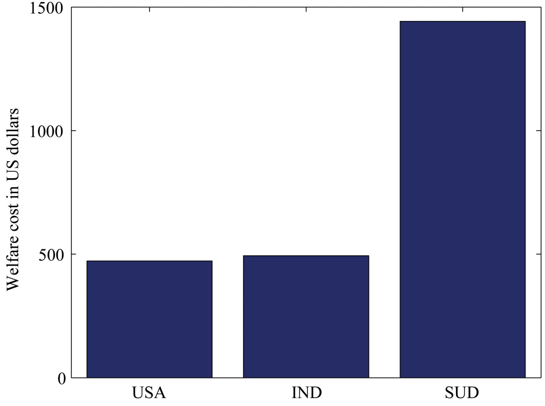

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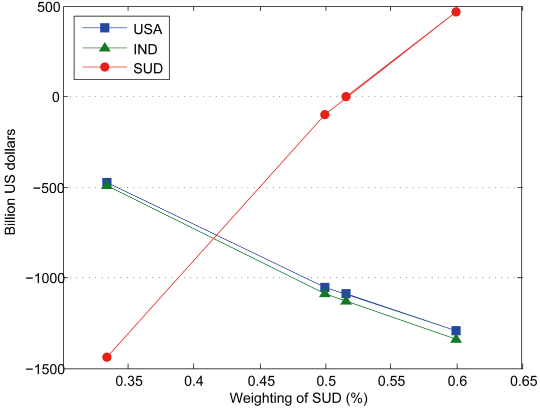
Discounted welfare costs, 2000-2050 (in billion USD) Increase the weighting of the poorest



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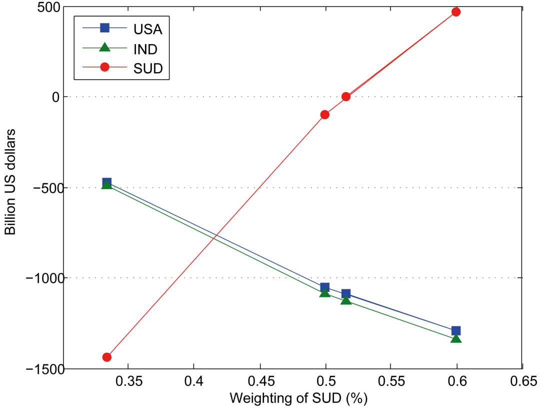

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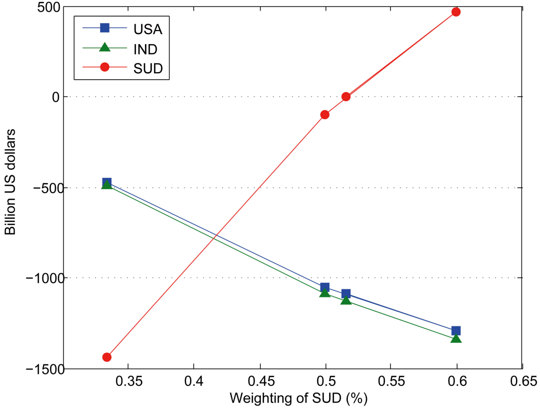

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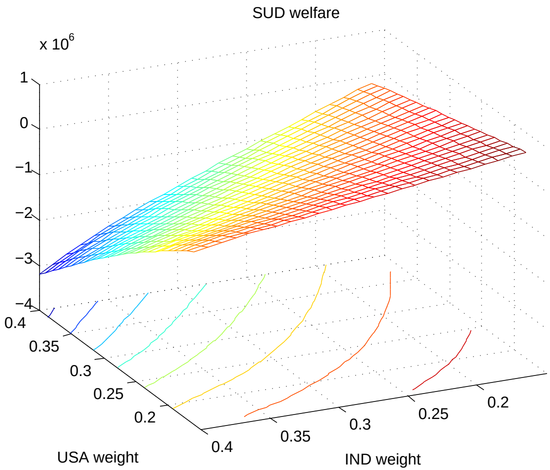

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- the higher the weight the lower the cost.

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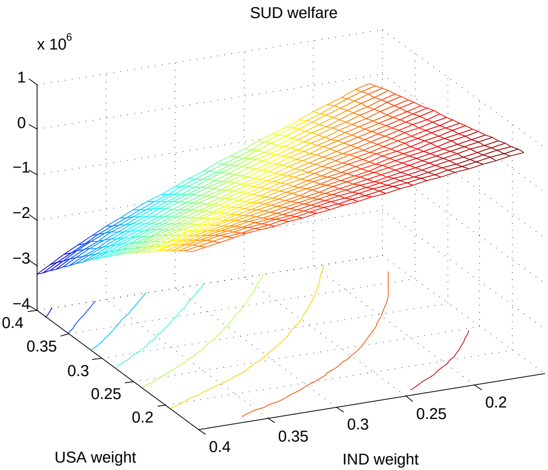

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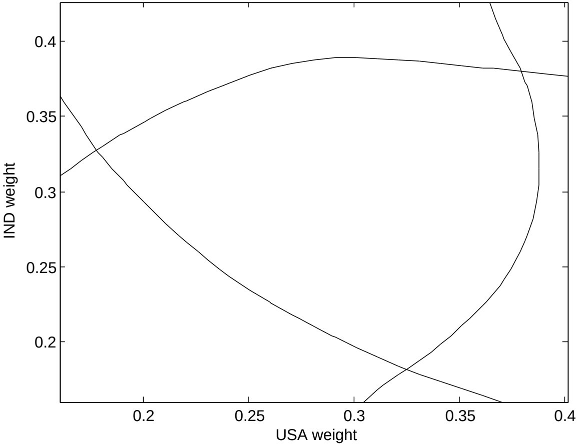
Acceptable weights



- 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.

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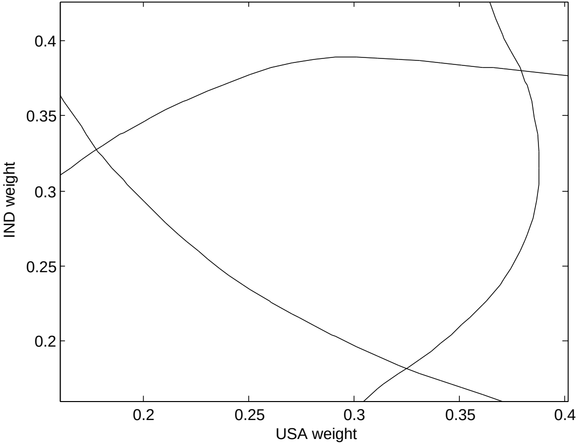

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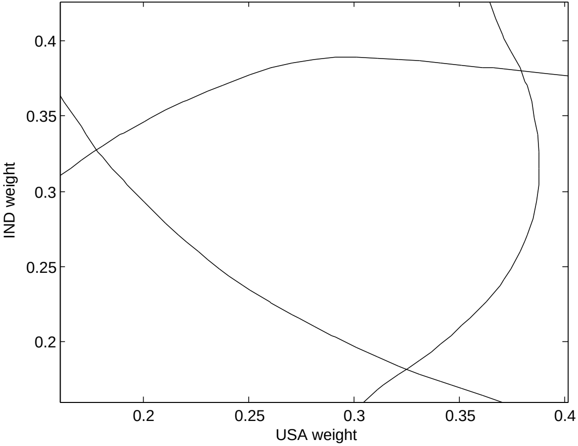

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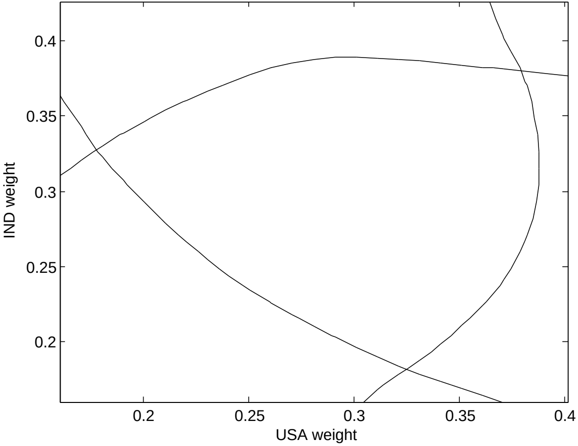

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Further research

- 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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