ORDECSYS

UNIVERSIDAD ADOLFO IBÁÑEZ

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Potentials of Negative Emissions in the Design of Climate Agreements[1]

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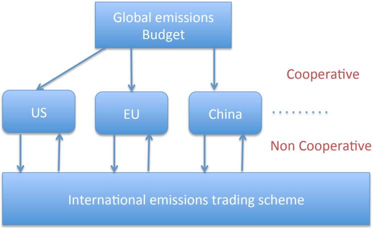
Adressed questions

1. How to design a fair agreement among groups of countries (compatible with a 2^{o}C target in 2100)?
2. What could be the role played by Carbon Dioxyde Removal activities in the design of such agreements?
3. How each country will use its allocations and CDR potentials? What will be the associated costs for each country?

Meta-games for climate negotiations



The payoff (welfare loss) of player j at equilibrium satisfies :

$$\min_{\omega_j} \left\{ \sum_{t=0}^{T-1} \pi_j^t(\mathbf{e}^t(\Omega^t)) + \kappa_j^t(\mathbf{v}_j^t) - \tilde{p}^t(\Omega^t)(\omega_j^t - \mathbf{e}_j^t(\Omega^t)) \right\},$$

subject to actions chosen by the other players and under the budget sharing constraint

$$\sum_{t=0}^{T-1} \omega_j^t \leq \theta_j \mathtt{Bud} + \sum_{t=0}^{T-1} \mathbf{v}_j^t.$$

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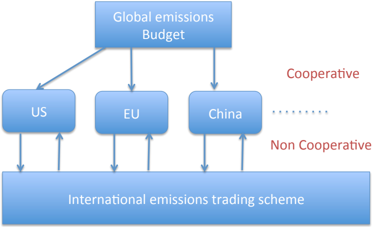

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Applying standard Kuhn-Tucker multiplier method, with multipliers $\nu_j \geq 0$, we obtain the following first order necessary conditions for a Nash equilibrium $\forall t \ \forall j$:

$$0 \leq \frac{\partial}{\partial v_j^t} \kappa_j^t v_j^t - \nu_j \qquad 0 = v_j^t \left(\frac{\partial}{\partial v_j^t} \kappa_j^t v_j^t - \nu_j \right)$$

$$\omega_j^t \left(- \frac{\partial}{\partial \sum_k q_k^t} \gamma_j \left(\sum_k q_k^t \right) + \tilde{p}^t(\Omega^t) + \frac{\partial}{\partial \omega_j^t} \tilde{p}^t(\Omega^t)(\omega_j(t) - e_j^t(\Omega^t)) + \nu_j \right) = 0.$$

$$0 \leq \mathtt{Bud}_j - \frac{1}{2} \sum_{s=0}^{t-1} \delta^{s+1} (\omega_j^s + \omega_j^{s+1} - v_j^s - v_j^{s+1})$$

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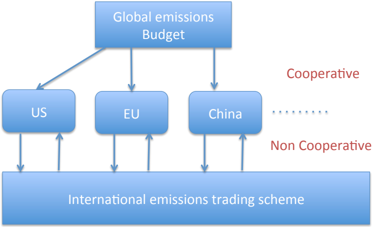

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Abatement cost functions π are estimated through statistical emulation on a large set of GEMINI-E3 simulations

A noncooperative meta-game approach

Input Global budget *Bud* and allocations among countries (i.e., θ_j)

Model Minimize the economic impacts for each country by deciding:

1. How to use the budget on the horizon
2. Activity of CDR
3. Permit sales and buyings on the trading market

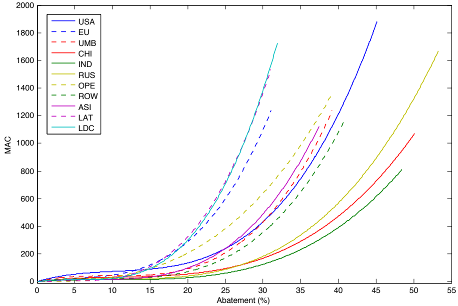
Output Emissions, CDR, Permit exchanges, Permit prices, % of welfare losses, ...

$\Rightarrow$ By testing different allocations, one can find a fair burden sharing. For example if we adopt a Rawlsian approach to distributive justice, the optimal game design problem consists in finding the θ_j's in such a way that one minimizes the largest welfare loss among the countries.

Estimation of the abatement cost functions

- We use the CGE model GEMINI-E3 as a the provider of data for the estimation of the abatement cost functions for each group of countries
- Estimations are based on statistical emulations of a sample of 200 GEMINI-E3 numerical simulations (6 periods $\times 11$ = nb estimations)
- The abatement costs are polynomial functions of degree 4 in the country abatement level

$$AC_j(t) = \alpha_1^j(t)\, q_j(t) + \alpha_2^j\, q_j(t)^2 + \alpha_3^j(t)\, q_j(t)^3 + \alpha_4^j(t)\, q_j(t)^4. \qquad (1)$$



Robust game

We apply Robust Optimization techniques to take into consideration uncertainty in estimating abatement costs with GEMINI-E3

Table: Uncertainty assumptions for abatement cost

	2040	2050	2070	2100
Type 1: Robust low	2.5%	5.0%	7.5%	10.0%
Type 2: Robust high	5.0%	10.0%	15.0%	20.0%

And compute robust equilibrium solutions.

Assumptions

- Safety cumulative global emission budget: 1170 Gt of CO_2
- Total levelized cost for BECCS: \$60/t-CO_2
- Total levelized cost for DAC: \$300/t-CO_2
- Carbon storage potential per region in Gt CO_2:

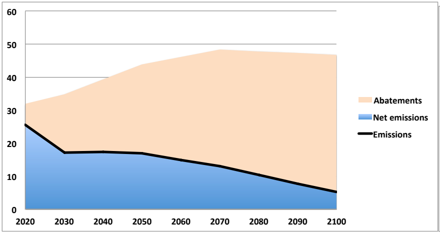
United States of America	24.0
European Union	37.5
China	30.5
India	20.0
Russia	126.5
Gulf Cooperation Council	86.0
Other energy exporting countries	23.0
Rest of asian countries	46.0
Latin America	40.5
Rest of the World	23.0
World	447.0

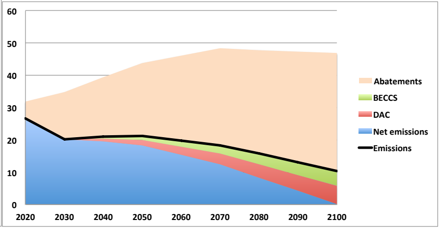
- Land-use potentials for BECCS are also modeled.

Impact of CDR (deterministic case)

Table: CO_2 price and welfare cost assuming a 3% discount factor

DAC & BECCS	Without	With
Discounted CO_2 price (ref. 2020) in $\$_{2010}$	369	218
Discounted World cost in % of discounted GDP	3.7%	2.3%





Impact of CDR (deterministic case)

Table: Burden-sharing and welfare cost with Rawlsian rule without robustification

	Budget share	Welfare cost[a]	Components of welfare cost[a] Abatement	DAC	BECCS	GTT	Exchange[a]
USA	10.16%	2.32%	1.86%	0.11%	0.04%	-0.01%	0.32%
EUR	6.75%	2.32%	0.79%	0.18%	0.04%	-0.46%	1.78%
CHI	19.84%	2.32%	3.72%	0.11%	0.03%	-0.66%	-0.87%
IND	6.34%	2.32%	3.40%	0.19%	0.08%	-1.37%	0.02%
RUS	3.51%	2.32%	3.19%	2.48%	0.25%	2.01%	-5.60%
GCC	5.78%	2.32%	3.26%	2.42%	0.04%	5.69%	-9.08%
OEE	16.69%	2.32%	1.73%	0.12%	0.03%	1.05%	-0.60%
ASI	12.30%	2.32%	1.42%	0.12%	0.03%	-0.72%	1.48%
LAT	1.69%	2.32%	1.83%	0.79%	0.19%	0.13%	-0.62%
ROW	16.93%	2.32%	2.59%	0.17%	0.04%	0.34%	-0.82%
World	100.00%	2.32%	2.05%	0.26%	0.05%	0.00%	0.00%

[a] Discounted welfare cost in % of discounted GDP

[b] Negative (positive) values are for net sellers (buyers)

From 2 to 1.5^{o}C target (deterministic case)

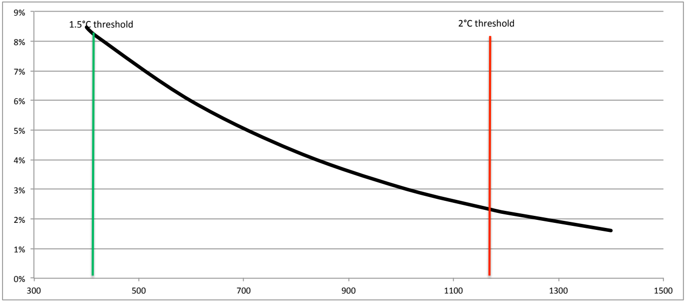


Figure: Discounted global welfare cost in % of discounted GDP with respect to carbon budget in Gt CO_2

Robust agreements

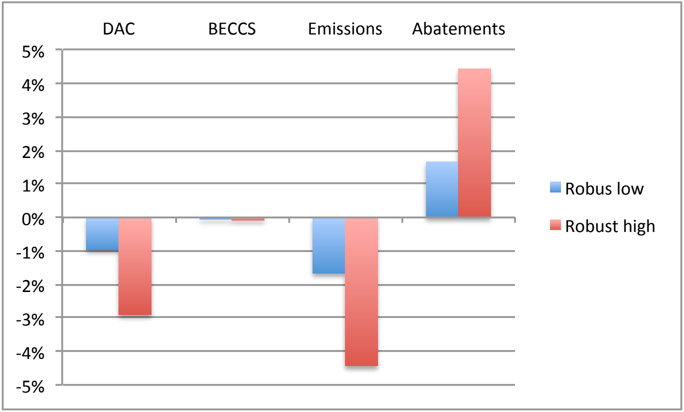


Figure: Global changes, compared to deterministic case in relative terms, on DAC, BECCS, emissions and abatements.

Robust agreements

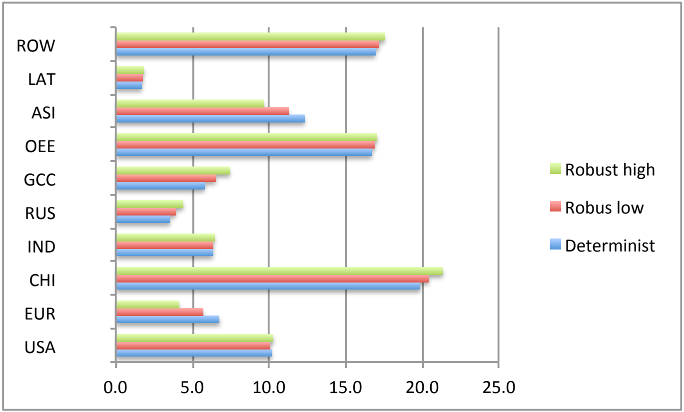


Figure: Deterministic and robust allocations (in % of Budget)

Conclusion

- It is possible to design fair agreements (eg, equalizing welfare costs between coalitions)
- The implementation of a tradable permits market is crucial as it allows equalization of marginal abatement costs and reduction of welfare losses
- CDR can play an important role in the transition towards low carbon economy and has to be considered in climate negotiations. It has to be considered as a new resource offering a future to fossil fuels
- Exporting countries (eg, GCC, Russia) should be proactive in climate negotiations promoting the implementation of a permit market and developing CDR capacities