# Lecture 1C: Policy games--Cooperative climate agreements: Cooperative or non-cooperative games?

**International policy steps**

- Copenhagen Accord (2009), **2** °C
- Paris (2015), 2 °C, but **1.5**°C needed to prevent future weather extremes
  - reduce emission to half until 2030, and **no** (new) emission by **2050**
  - re-evaluation of countries' effort in 2020, 2023,,,COP meetings

**Success or failure?**

- no enforceable agreements
- we have **already 40%** emission more than 1990
- needs substantial reduction in emission from coal (carbon budget threshold)
- we are **likely to move toward 3**°C**, or higher**

**Alliances, coalitions, and institutions**

- Formed in Paris (2015), Bonn 2017, and Katowice 2018
- Multi lateral institutions are involved: UN, ILO, WB, IMF

# Lecture 1C: Lack of Success --Cooperative climate agreements or non-cooperative games

=> **To explain this lack of success:**

- Less progress made through games (lock-ins, irreversibilities, delaying forces, home-based policies)
- Environmental games? (see game theory, work with Di Bartolomeo et al., 2018)
- See our book Nyambuu/Semmler , ch 10,
- See also Raphaele Chappe, Handbook (Bernard/Semmler)
- Cooperative/Noncooperative games, two extreme cases
- Coalition formation (Heal)

# Lecture 1C: Lack of Success –Motivation: Non-cooperative games

- The Joint Exploration of a Productive Asset: A Game-Theoretic Approach (Benhabib and Radner, 1988)
- Two or more agents exploit a common productive asset, lack of long term cooperative behavior
- Best response to an agent consuming maximally is also to consume maximally

$$\int_0^t e^{-rt} c(t)\,dt$$

$$\dot{y}(t) = m[y(t)] - c(t)$$

# Lecture 1C: Negative externality; Cooperative climate agreements or non-cooperative games

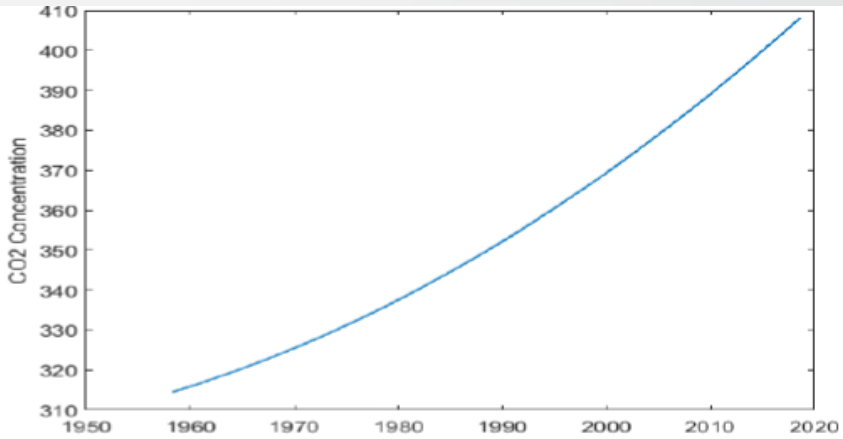
**see paper, B. Fard,** Di Bartolomeo, W. Semmler, SCED, 2022, Nyambuu/Semmler, ch.10

How can one get to international agreements?

- Environmental Games deal with the free rider problem: one party removes pollution (and the damages from it), the other party enjoys this without cost
- The same with greenhouse gases (GHGs): On country pursues mitigation policy the other country enjoys the clean air and the avoidance of climate disasters; thus the mitigation implementation leads to conflicts. (Böhringer, 2014; Nordhaus, 2008, 2015)
- How can one obtain a strong coalition through which international agreements can be enacted? Given the international need for cooperation, what are the incentives to participate (see Nordhaus) or cooperate, through a cooperative game? Through coalition formation?
- Here is a model of non-cooperative and cooperative games, which one reduces CO2 emission more, what is the role of short-termism of politicians: Our approach aims to quantify the impact of:
  1. Cooperative and non-cooperative behavior (has different $CO_2$ concentration)
  2. What is the role of short-termism of climate policies
- For this purpose, in the context of environmental game, we introduce Non-linear Model Predictive Control to formalize moving horizon strategic interactions between several policymakers.

# Introduction:

- $CO_2$ concentration (1958-2019)
  [Source: NOAA Earth System Research Laboratories, ESRL
  Fig. 1




- To limit global warming, we need to limit the total cumulative global emissions of $CO_2$. Emissions scenarios which limit the concentration level up to 450 ppm are likely to lead to 2°C above pre-industrial temperatures by 2100, while scenarios that reach a concentration of 650 ppm, achieve 3°C (IPCC, 2018).

- International cooperation (or significant participation) is an important way to internalize global externalities. However, according to Nordhaus (2021), the problem of free-rider should be solved by a partnership between players such as a climate club --- can it lead to a penalty on non-participants?

- In NMPC, different lengths of the time horizon affects the dynamics and choosing different decision horizons can be discussed as a different degree of rationality or myopia, see Wong et al. (2015); Bartolomeo et al. (2018); Saltari et al. (2021) and Bartolomeo et al. (2021).

# Lecture 1C: Cooperative climate agreements or non-cooperative games

## Literature

- We follow a traditional approach which integrates the economic activity and the climate system to evaluate the effect of mitigation policies on GHG emissions (integrated assessment models).
- Among these, the most related are those considering "different nations" as environmental policymakers and different scenarios, e.g., non-cooperative vs. non-cooperative. Our theoretical framework is largely based on:

1. Greiner and Semmler (2005) and Greiner et al. (2014).
2. On the methodological ground the paper is related to the literature on model predictive control, which is experiencing a growing interest in economics see Grüne et al. (2015); Van den Broek (2002) and Di Bartolomeo et al. (2018).

- In the above perspective, we use as a benchmark for comparing the results obtained from the Regional Integrated model of Climate and the Economy (RICE) developed by Nordhaus and Yang (1996).

# Lecture 1C: Cooperative climate agreements or non-cooperative games

## Technical Note: The use of NMPC for Strategic interactions among multiple policymakers

- NMPC computes finite-horizon optimal trajectories in order to find the infinite-horizon optimal trajectory.
- Policy equilibrium is a situation where, at every instant of time, each policymaker has no incentive to vary its decision given that of the other (Nash equilibrium).
- Given an initial value, NMPC for strategic interactions among multiple policymakers generates solutions on a finite time horizon by iteratively as follows:

1. The policymakers' problems involve the repetitive solution of an optimal control problem at each sampling instant $t \in \mathbb{R}_0^+$, in a receding time horizon fashion, and the outcome is a vector of $T$ controls. (The length $T$ defines the agent's policy horizon).
2. This procedure for both policymakers continues until a fixed point is found, where optimal strategies are mutually consistent. so, the simultaneous solution of the problems for both agents provides a tuple for both controls.
3. The set of all the tuples represent our policy equilibrium

- It is worth noting that for $T \to \infty$, our equilibrium collapses to the Nash open-loop equilibrium. However, strategies based on different policy horizons will lead to different outcomes.

# Technical Note: Prominent points of this research

1. Considering Greiner and Semmler (2005) and Greiner et al. (2014), both papers use a non-linear model predictive approach to approximate optimal control solution in a single player setup. By contrast, we use model predictive control to formalize moving horizon strategic interactions between several policymakers.

2. We introduce a small heterogeneity in the disutility, $\gamma$, gamma to avoid symmetrical solutions that may "hide" some potentially relevant effects.

3. Our work also has an added value from a methodological point of view. It introduces the strategic model predictive control approach in the context of environmental economics, i.e., the possibility of considering the relevance of a limited policy horizon in a strategic context.

# Lecture 1C: Cooperative climate agreements or non-cooperative games

## Technical Note: The model; Non cooperative Form

- Formally, the use of non-renewable energy in country $i \in \{1,2\}$ $(x_i(t))$, leads to an increase of $CO_2$ global concentration $(g(t))$, i.e. filling up carbon budget,

$$\dot{g}(t) = \beta\big(x_1(t) + x_2(t)\big) - \mu \cdot g(t) \text{ with } g(0) = g_0 \qquad (1)$$

- $\beta \in (0,1)$ gives that portion of $CO_2$ that is not absorbed by oceans and $\mu \in (0,1)$ is the inverse of the atmospheric lifetime of $CO_2$

- Social preferences of our model are captured by a simple instantaneous utility function of the class of those used by, e.g., Byrne (1997) or Greiner *et al.* (2014)

- The solution involving non-linear model predictive control can be formally described as follows. In each instant of time $t \in \mathbb{R}_0^+$, given the policy of the opponent $j$, each policymaker $i$ solves the following problem:

$$\max_{x_i} \int_t^{t+T} e^{-\rho t} U_i(t)dt \quad i \in \{1,2\} \qquad (2)$$

s.t. equation (1) and $g(t) = g_t$

$$U_i(t) = \frac{x_i(t)^{1-\sigma}(g(t)-\bar{g})^{-\gamma(1-\sigma)}-1}{1-\sigma} \qquad i \in \{1,2\} \qquad (2)$$

where $\bar{g}$ is the pre-industrial level of $CO_2$ concentration; $\gamma >$ is the (dis)utility of the $CO_2$ concentration exceeding the pre-industrial level, i.e., $\gamma$ expresses the effect of disutility (or the disaster effects) on our well-being; $\sigma > 0$ is the inverse inter-temporal elasticity of substitution of consumption between two points in time.[11]

# Lecture 1C: Cooperative climate agreements or non-cooperative games

## The Model: Cooperative Form (Nash)

- We also introduce a different policy equilibrium, where the idea of policy horizon is kept, but externalities are internalized by international coordination. We solve a problem like (2), where $x_1$ and $x_2$ are set to jointly maximize a sort of Nash product:

$$N(t) = (U_1(t))^{\omega} (U_2(t))^{1-\omega}$$

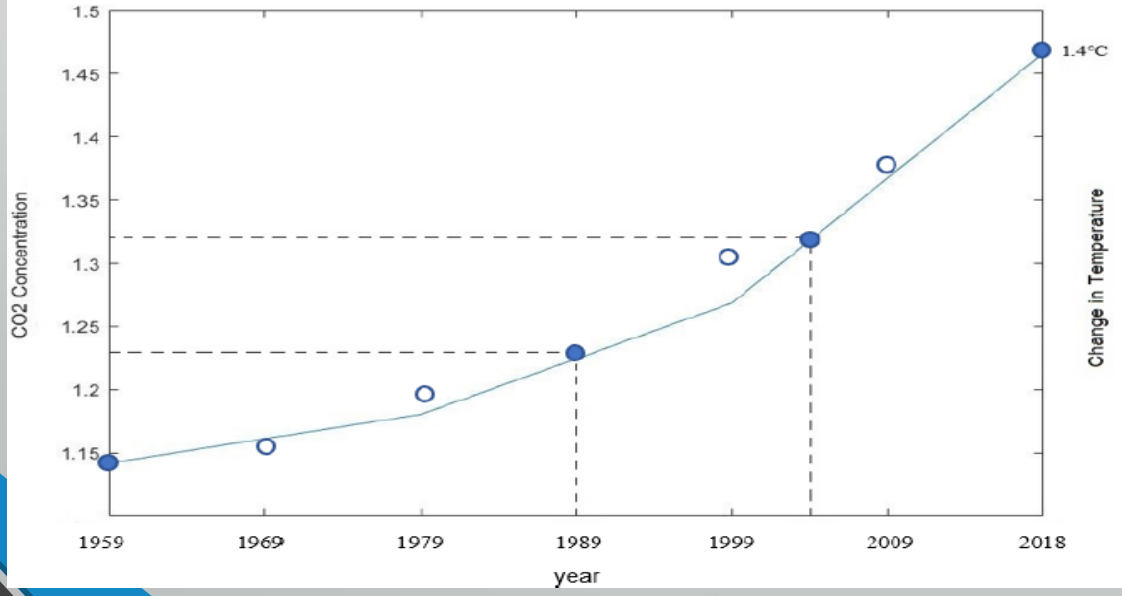
- where $\omega$ and $1-\omega$ measure policymakers' relative bargaining powers. In the simulation, we assume an equal bargaining power, i.e., $\omega = 1/2$.

# Lecture 1C: Cooperative climate agreements or non-cooperative games

## Observed CO2 Concentration 1959-2019

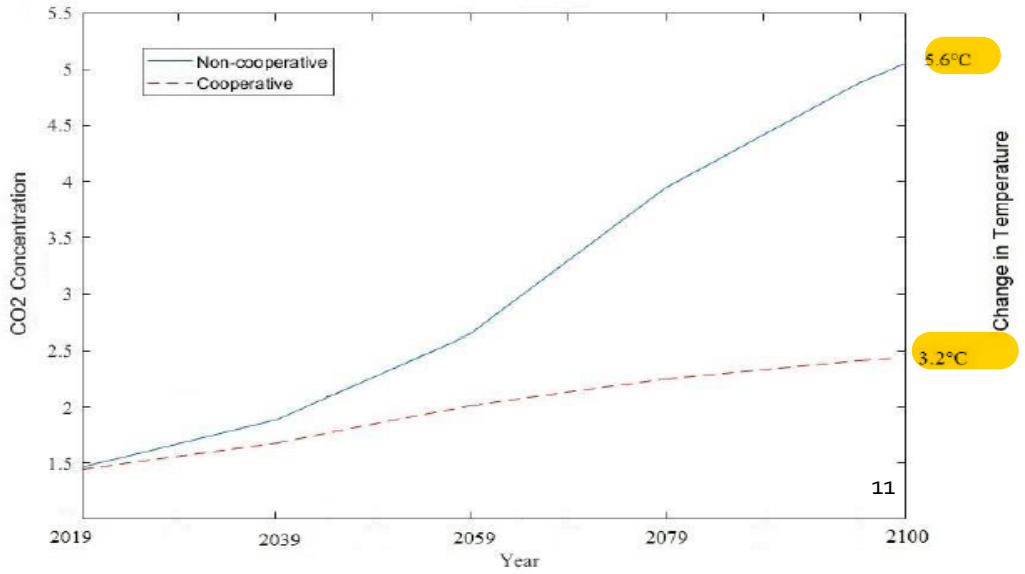
- This optimization is important to verify the accuracy of numerical procedures in our research.
- Fig. 2 shows the evolution of $CO_2$ concentration (left scale) and of the global mean temperature (right scale
- The curve shows good compatibility with observed data. The marked-time points are just indicative, the calibration is based on monthly data (cf. Fig 1).

Fig. 2




## Prediction of CO2 concertation 2019-2100

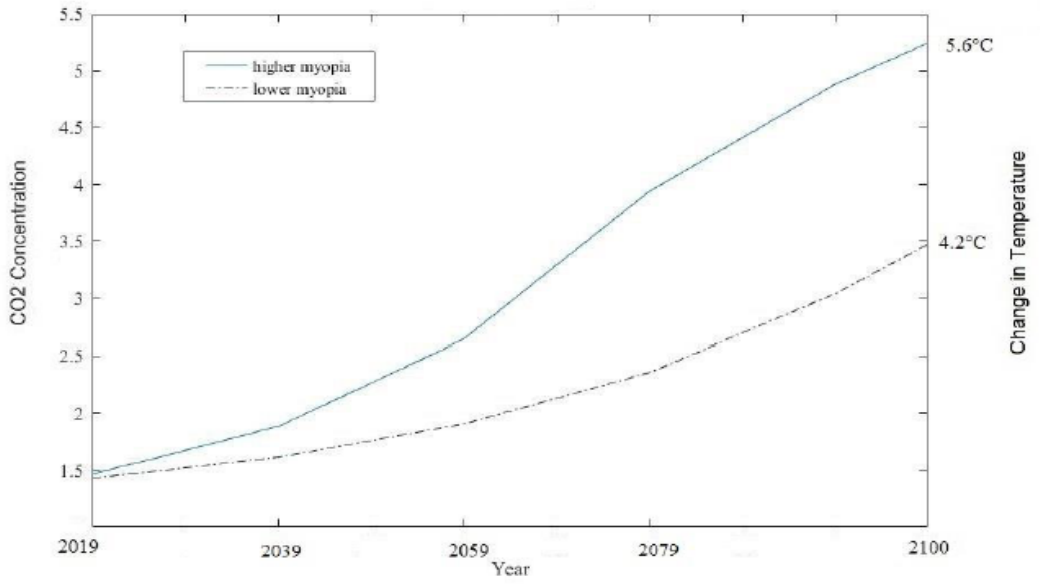
- Outcomes show the worst prediction for non-cooperative strategies while coordination is particularly effective in reducing concentration by internalizing the global externalities.
- comparing our results with RICE model, In 2100, the RICE model predicts lower level of $CO_2$ concentration under both scenarios. This difference can be explained by policymakers' short termism in our model and/or considering the Nash equilibrium in a finite game with perfect information in RICE model while, by contrast, we assume model predictive control to formalize moving horizon strategic interactions between several policymakers.
- Fig.3



# Policy myopia (Short-termism)

$CO_2$ concentration and policy; higher myopia(short-termism) T=3 and lower myopia T=4, respectively).

Fig. 3




- policymakers could face political economy constraints incentivizing them to have short-time horizon decisions.
- The model predictive control is a suitable technique to deal with this issue.
- The length of the policymaker's horizon can be considered an exogenous parameter, which describe the political economy constraint by governments (Di Bartolomeo et al., 2018).
- The figure shows that myopic policies will lead to a higher level of $CO_2$ concentration compared to the less myopic ones.
- It implies that this tendency to short-termism, may lead to the under-evaluating the cost of the level of $CO_2$ Concentration compared with less myopic policymaker.

# Lecture 1C: Cooperative climate agreements or non-cooperative games Conclusions

- We have modeled two extreme cases, but actual negotiations have made some progress
- Non-cooperative games, being driven by short-termism, lead to higher $CO_2$ emission, as compared to cooperative games
- The history of practical negotiations shows a mixture of both, see Lecture 2 A
- Further, a coalition formation is needed as suggested by Geoffrey Heal, to take place via the UN: Coalition of EU, US, India, and China the other will join (see Paris 2015 agreements).
- Yet burden sharing and fair transition is the biggest issue, funding for low-income countries (since Copenhagen),
- Financing: Sachs; partly grants partly loans.