An Evolutionary IEA Game: the Evolution of Abatement Strategies

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Background

- Kyoto protocol vs. Copenhagen Accord: paradigm shift?
- top-down, binding "targets and timetable" agreement
- bottom-up, voluntary "pledge and review" accord
- players *adapt* their abatement behaviour to the payoff differentials perceived through pairwise (i.e. bilateral) and multilateral interactions
- study the evolution of a certain ecology of emission-reductions strategies

Outline

- Social Dilemmas/ Tragedy of the Commons
- Literature review
- IEA evolutionary game
- IEA game with state-independent abatements
- IEA game with state-dependent abatements
- Concluding remarks

Global Commons

- tension between suboptimal equilibrium "defection" and optimal non-equilibrium "cooperation"
- mechanisms to "evolve" cooperation:

1. direct reciprocity
2. indirect reciprocity: reputation
3. reward/punishment: sanctions
4. local (spatial) interaction: cooperate with cooperators

- "local" commons: E. Ostrom work on the emergence of institutions to deal with CPR
- "global " commons: GHG stock admissable in the atmosphere, quality of environment, biodiversity ?

Literature overview

- Seti and Somanathan (1996): CPR game, Replicator Dynamics, stock-dependent harversting rules: cooperators, defectors, punishers: positive fraction of cooperators
- Xepapadeas (2005): CPR, coupled dynamics, stock-dependent auditing probabilities: oscillations
- Iwasa (2007, 2009): shallow lake: coupled dynamics of socio-economic norms(i.e. phosphorus discharge levels) and lake quality: “social pressure” , costs incurred by the non-complying players
- Arce (2004): "leading-by-example" in an IPG game: partial cooperation is an ESS

Conditional Strategy: Reciprocity

- *"commit to an emission reduction target x%* **unilaterally** *and upgrade to a higher target y%* **provided that** *other players* **match** *this contribution".*

- UNFCC, pledges as of 31 january 2010:

1. EU: 20%/30% (iff matched)
2. Australia: 5%/15%(if stabilization at 450 ppm fails)/25% (iff stabilization reached)
3. Japan: 25% provided agreement reached on "ambitious" targets
4. Non-Annex I: carbon intensity targets: China :40%/45% India 20%/25%

Emmission reduction strategies

- Unconditional abatement strategies:

$$\begin{aligned} \text{“\textit{Social optimum}”}\ (E) &\quad : \quad p_E \\ \text{“\textit{Cooperate}”}\ (C) &\quad : \quad p_H \\ \text{“\textit{Defect}”}\ (D) &\quad : \quad p_L \\ \text{“\textit{Nash}”}\ (N) &\quad : \quad p_N \end{aligned} \tag{1}$$

- Conditional strategy:

$$L = \left\{ \begin{array}{c} p_H \text{ if opponent chose } p_L, p_H \text{ or } p_N \\ p_E \text{ iff opp choice was } p_E \end{array} \right\} \tag{2}$$

Evolutionary IEA Games

- stage game:

$$P = \begin{array}{c} \\ E \\ C \\ D \\ L \end{array} \begin{bmatrix} E & C & D & L \\ p_E, p_E & p_E, p_H & p_E, p_L & p_E, p_E \\ p_H, p_E & p_H, p_H & p_H, p_L & p_H, p_H \\ p_L, p_E & p_L, p_H & p_L, p_L & p_L, p_H \\ p_E, p_E & p_H, p_H & p_H, p_L & p_E, p_E \end{bmatrix} \tag{3}$$

- stage game payoffs:

$$\pi_i(p_i, p_j, S) = U_i(S, p_i, p_j) - mc_i \cdot p_i, fori = E, C, D, L \tag{4}$$

- utility function

$$U_i(S, p_i, p_j) = (1/S) + (p_i + p_j) \tag{5}$$

Evolutionary IEA Game (cont 'ed)

- asymmetric marginal costs:

$$mc_L < mc_j, j = E, C, D \tag{6}$$

- fractions of L, E, C, D rules evolution follow the Logit Dynamics:

$$x_{i+1} = \frac{e^{\beta\pi_i(p_i,S)}}{\sum_i e^{\beta\pi_i(p_i,S)}}, i = E, C, D, L \tag{7}$$

- The stock of GHG(S) evolves according to a simple inflow-outflow difference equation appended with a nonlinear "feedback" term:

$$S_{t+1} = (1+\alpha)S_t - G_t S_t + \sigma(S_t), \sigma(\cdot) \text{ nonlinear} \tag{8}$$

- the average GHG abatement percentage:

$$G = \sum_i (\mathbf{x})_i p_i, \;\; i = E, C, D, L \tag{9}$$

State-independent abatements

- strategy set

$$\begin{aligned} &\text{“}\mathit{Social\ optimum}\text{”}\ (E) : p_E = e \\ &\text{“}\mathit{Cooperate}\text{”}\ (C) : p_H = h \\ &\text{“}\mathit{Defect}\text{”}\ (D) : p_L = l \end{aligned} \tag{10}$$

$$L = \left\{ \begin{array}{c} p_H = h, \text{ if opponent played } C, D \\ p_E = e \text{ iff opponent strategy } E \end{array} \right\} \tag{11}$$

- marginal costs

$$mc = \left\{ \begin{array}{c} c_h = m, \text{ for strategy } C, D, E \\ c_l = n \text{ for } L \text{ strategist} \end{array} \right\}; n < m. \tag{12}$$

- Dynamical system

$$\left[\begin{array}{c} (\mathbf{x})_{i,t+1} = \frac{e^{\beta(A\mathbf{x})_i}}{\sum\limits_i e^{\beta(A\mathbf{x})_i}}, i = E, C, D, L \\ S_{t+1} = (1+\alpha)S_t - G_t S_t + \frac{rS_t^q}{p^q + S_t^q}, G_t = xl + yh + (z+w)e \end{array} \right] \tag{13}$$

Long-run behavior

Parameterization of the model

- initial stock of GHG $S = 500$
- strategic space consisting in: $l = 0.01, h = 0.02, e = 0.03$
- marginal abatement costs $n = 1$ and $m = 2$
- business-as-usual emissions growth rate $\alpha = 0.01$
- intensity of selection/responsiveness to payoffs differences $\beta = 6$
- remaining model parameters: $r = 0.5, p = 1, q = 1.$

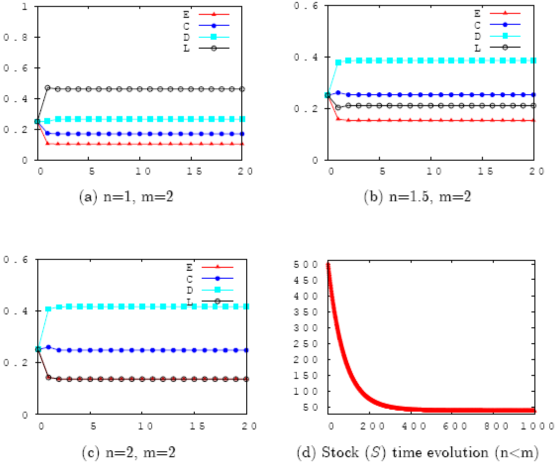


Figure 1: Co-evolution of strategies and GHG concentration for state-independent emmisions cut pledges. Panel (a)-(c): Evolution of fractions of different strategies for various cost asymmetries. Panel (d) very long transient for emmisions stock decaying and stabilization

State-dependent abatements

- *GHG abatement* rates

$$p_E(S) \geq p_H(S) \geq p_L(S) \geq p_N(S)$$

- e.g. a linearly increasing function of the existing stock

$$p_i(S) = (p_i S)/100, i \in \{E, H, L\}$$

- co-evolutionary dynamics b\w strategies and state

Co-evolutionary dynamics: behavior&state

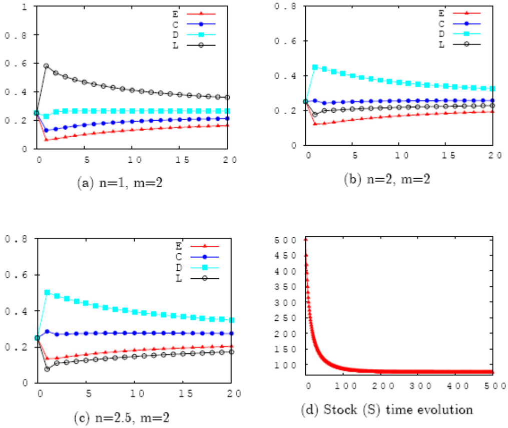


Figure 2: Co-evolution of strategies and GHG concentration for state-dependent emmisions cut pledges. Panel (a)-(c): Evolution of fractions of different strategies for various cost asymmetries. Panel (d) short transient for emmisions stock decaying and stabilization at around 100

Alternative utility function

- Mäler et. al.(2003) specification
- countries weigh the benefits of emissions reductions (i.e. stable climate) versus the detrimental effects such emissions cuts may have, as least on short run, on GDP and welfare:

$$U_i(p_i,p_j,S) = p_i + p_j - a(S - (p_i + p_j))^2$$

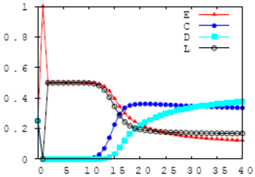
- state-independent abatement rates
- Conditional strategy: the leader exactly matches the contribution of the opponent, i.e. there is no unilateral emission cut pledge.

Alternative utility function

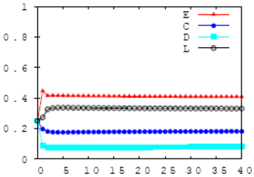
- Stage game payoff matrix

E	C	D	L
2e-a(S-(2e))^2	e+h-a(S-(e+h))^2	e+l-a(S-(e+l)))^2	2e-a(S-(2e))^2
h+e-a(S-(h+e))^2	h+h-a(S-(h+h))^2	h+l-a(S-(h+l))^2	h+e-a(S-(h+e))^2
l+e-a(S-(l+e))^2	l+h-a(S-(l+h))^2	l+l-a(S-(l+l))^2	l+h-a(S-(l+h))^2
e+e-a(S-(e+e))^2	h+h-a(S-(h+h))^2	l+l-a(S-(h+l))^2	e+e-a(S-(e+e))^2

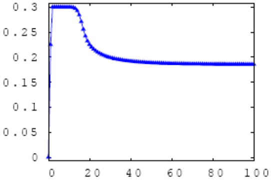
- initial stock $S = 5$,BAU growth rate of emissions is set to 0.2
- strategy set: $l = 0.1$, $h = 0.2$, $e = 0.3$
- Players/countries are only moderately rational in updating their pledges to the offers of the opponents,i.e. intensity of selection is set to $\beta = 6$



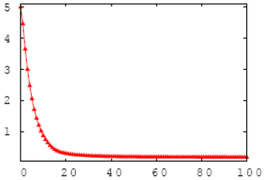
(a) a=5



(b) a=0.01



(c) Average pledge (G) time path



(d) GHG stock (S) time evolution

Figure 3: Co-evolution of strategies, average emmisions cut, GHG concentration for Maler type of utility. Panel (a)-(b): Evolution of fractions of different strategies for various cost asymmetries. Panels (c)-(d): evolution of average cut pledges and stock of GHG

Conclusions and future directions

- evolutionary environment where countries constantly revise their submitted pledges through bilateral or multilateral interaction
- mixed support for a 'lead-by-example'strategy
- conditional strategy: mechanism for evolving cooperation in order to voluntarily provide the *global* public good of climate stability.
- model explicitly a 2-stage "matching" game: first countries play the "matching rate" game then the (unilateral) reduction target per se