Towards a Self-Enforcing Climate-Change Treaty

Prajit K. Dutta, Economics Dept., Columbia University

Roy Radner, Stern School of Business, New York University

4th Workshop on Game Theory in Energy, Resources and Environment

Montreal, November 29, 2012

1. Climate change ("global warming") is international in scope, requiring international, or transnational, cooperation.

2. Dynamics are long-lasting, and reversibility is very slow.

3. Because of the long time-scale (point 2), intergenerational equity issues are important.

1. Climate change ("global warming") is international in scope, requiring international, or transnational, cooperation.

2. Dynamics are long-lasting, and reversibility is very slow.

3. Because of the long time-scale (point 2), intergenerational equity issues are important.

4. Because of significant international differences in population, rates of population growth, and levels of economic development, issues of international equity are also significant.

5. Although the scientific basis of climate change is qualitatively established, there is considerable uncertainty (and disagreement) about its dynamics and consequences.

The absence of world government implies the need for a **self-enforcing treaty** to curb global warming.

We model the situation as a **dynamic game** in which **the players are the world's countries**.

There will be many Nash equilibria of this game.

One of them is the current trajectory - **"business as usual."**

A self- enforcing treaty is also a (subgame perfect) Nash equilibrium of the game.

One equilibrium is the current trajectory - "Business as Usual" (BAU).

A self- enforcing treaty is also a (subgame perfect) Nash equilibrium of the game.

*****

We search for self-enforcing treaties that are Pareto-superior to BAU.

[More ambitious - second-best? first-best?]

Outline of Rest of Talk

A climate-change model

Equilibria and Global Pareto Optima of the climate-change model.

Foreign aid

Trade sanctions

Going foward

A Climate-Change Game - 1

I players, and time is discrete. Each player is a sovereign country or other sovereign jurisdiction, e.g., the European Union. The first basic variables are:

$$
\begin{aligned}
t &= 0, 1, 2, \text{...ad inf, time period .} \\
i &= 1, ..., I, \text{ country (player).} \\
\mathbf{e}_i(t) &= \text{"energy input" of country } i \text{ in period } t \text{ (a vector),} \\
a_i(t) &= \text{emission of greenhouse gas (GHG)} \\
&\quad\ \text{by country } i \text{ in period } t. \\
g(t) &= \text{the global stock of GHG at the beginning of period } t..
\end{aligned}
$$

Climate-Change Game - 2

Law of motion of GHG:

$$\begin{aligned} A(t) &= \sum_i a_i(t) = \text{ total emission of GHG in period } t, \\ g(t+1) &= \sigma g(t) + A(t), \qquad 0 < \sigma < 1 \text{(close to 1)}. \end{aligned}$$

Each country i has (in principle) access to J different technologies for producing energy.

$$\begin{aligned} e_{ij}(t) &= \text{ quantity of energy it produces by technology } j \text{ in period } t, \\ \boldsymbol{e}_i(t) &= \text{ vector with coordinates } e_{ij}(t). \end{aligned}$$

Asssume emissions by country i are determined by

$$a_i(t) = \sum_j \eta_j e_{ij}(t), \qquad \eta_j \geq 0, \text{ all } j.$$

Climate-Change Game - 3a

Production of output:

$$Y_{it}[\boldsymbol{e}_i(t)] = \text{ gross GDP of country } i \text{ in period } t.$$

e.g., $Y_{it}[\boldsymbol{e}_i(t)] = Y_i[K_i(t), P_i(t), \boldsymbol{e}_i(t)]$, where $K_i(t), P_i(t)$, are capital and labor (exogenous).

Damage from climate change to country i: Assume:

$$\text{damage to } i \text{ in period } t \; = \gamma_i g(t).$$

[Comments.]

Climate-Change Game - 3b

Energy from technology j in country i in period t is constrained by

$$0 \leq e_{ij}(t) \leq C_{ij}(t).$$

Capacity of technology j in country i can be expanded at constant marginal cost:

$$\begin{aligned} & \varphi_{ij}\left[C_{ij}(t) - C_{ij}(t-1)\right], \\ C_{ij}(t) \;\; \geq \;\; & C_{ij}(t-1) \geq 0. \end{aligned}$$

(Assumptions about "time to build"?)

Climate-Change Game - 4

The one-period payoff of country i in period t is:

$$u_i(t) = Y_{it}[\boldsymbol{e}_i(t)] - \gamma_i g(t) - \sum_j \varphi_{ij} \left[C_{ij}(t) - C_{ij}(t-1) \right],$$

and its total game payoff is

$$\begin{aligned} v_i &= \sum_{t \geq 0} \delta^t u_i(t), \\ 0 &< \delta < 1. \end{aligned}$$

The state of country i at the beginning of period t is $\mathbf{C}_i(t)$, the vector of individual energy capacities.

The state of the whole system at the beginning of period t is

$$\mathbf{s}(t) = [g(t), \mathbf{C}_1(t)], ..., \mathbf{C}_I(t)].$$

Climate-Change Game - 5

In period t each country i chooses its *action*,

$$[\mathbf{e}_i(t), \mathbf{C}_i(t+1)],$$

as a function of the history of states from periods 0 through t, subject to the relevant constraints. The sequence of those functions is the country's *strategy*.

As usual, a *Nash equilibrium* is a profile of strategies, one for each country, such that no country can increase its total game payoff by *unilaterally* changing its strategy.

We model a self-enforcing treaty as a Nash equilibrium of the game, possibly with some further restrictions.

We shall also subsequently expand the action spaces of the countries

CC Game - Equilibria and Pareto Optima - 1

Special assumtions:

For each country, production function Y_i is the same for all time periods.

Simplification of energy production model.

Continuum of Nash equilibria.

Business-as-Usual (BAU) equilibrium.

Refs: P. K. Dutta and R. Radner, 2004, 2006, 2009.

CC Game - Equilibria and Pareto Optima - 2

Business-as-Usual (BAU) equilibrium.

Global Pareto Optimal Outcomes

Nash reversion equilibria - reversion to BAU

Other equilibria

Renegotiation–proofness?

Need for expanding the game

Business-as-Usual (BAU) Equilibrium

BAU Equilibrium: Each country chooses its actions without regard to the negative externalities its emissions impose on other countries.

"Separability" assumptions on the model make the calculation of this equilibrium tractable. Country i uses a constant emission a_i* in each period,

This is a subgame-perfect Markov-Nash-Equilibrium.

Global Pareto Optimum (GPO)

For each country i let v_i be i's total game payoff, and let $x_i > 0$, such that $\sum_i x_i = I$. Given the vector $x = (x_i)$, the vector $v = (v_i)$ of feasible country payoffs is a Global Pareto Optimum (GPO) outcome if it maximizes

$$\text{Global welfare} = \sum_i x_i v_i$$

in the set of feasible vectors v. One can show that, for a GPO outcome, each country emits a constant emission $\hat{a}_i$ in each period.

One can show:

$$a_i{*} > \hat{a}_i \text{ for all } i.$$

1. Starting from a GPO, each country will want to increase its emissions **unilaterally** by at least a small amount.

2. There is an open set of vectors (x_i) of strictly positive weights such that the corresponding GPO is strictly Pareto superior to the BAU.

Trigger Strategy Equilibria with BAU Reversion

Given a GPO (with strictly positive weights) that Pareto dominates the BAU, suppose that the "norm" is for every country i to use its GPO emission: $a_i(t) = \hat{a}_i$. A defection occurs at period t if some country emits more than its GPO emission. After a defection, if any, every country uses its BAU emission forever: $a_i(n) = a_i^*$ for $n > t$. Call this a *trigger strategy profile with BAU reversion.*

For all discount factors sufficiently close to unity, the trigger strategy profile with BAU reversion is an equilibrium, and supports the GPO outcome.

Numerical Examples

Benchmark Case.

Initial year = 1998. $\delta = 0.97$

Damage cost coefficients from Fankhauser (1995).

"Cobb-Douglas" production functions.

For each country, population & capital stocks constant in time.

Calibrated so that BAU matches available data and estimates for 1998.

Welfare in 1990 US dollars. Emissions in gigatons of carbon.

Benchmark Case

Region	BAU emissions GtC	GPO emissions % decrease	GPO value % increase
USA	1.5	66	0.32
W Eur.	0.86	66	0.35
OHI	0.59	66	0.41
E Eur	0,74	72	0.54
MI	0.41	67	1.47
LMI	0.58	69	1.31
China	0.85	69	3.04
LI	0.66	69	1.37
total	6.18	68	0.63

Sensitivity Analysis

Discount factor	Fankhauser Damage Cost Coeff.	$5 \times$ Fankhauser Damage Cost Coeff.
$\delta = 0.97$	**68** **0.63**	**76** **3.95**
$\delta = 0.995$	**72** **1.98**	**83** **12.79**

Upper: GPO % emissions decreases

Lower: GPO % value increases

Extensions

Theory

- New model of energy production sectors (done)
- Changing production funtions
  - Exogenous population and capital growth (partly done)
  - Endogenous population and capital growth

Numerical calibration and examples, sensitivity analysis

Extensions

Theory

- New model of energy production sectors (done)
- Changing production funtions
  - Exogenous population and capital growth (partly done)
  - Endogenous population and capital growth

Numerical calibration and examples, sensitivity analysis

Nonlinearities, Uncertainty

Moving to a new equilibrium (treaty negotiation)

The Need to Expand the Game

A difficulty with the game as formulated. Although reversion to the BAU yields a mathematically valid subgame-perfect equilibrium, countries will be reluctant to do so. (Timing of costs and benefits, Barrett's criticism, failure of renegotiation-proofness?)

Need for "punishments for defection" that are more focused on the defector.

Possible remedies:

- Foreign aid
- Trade sanctions