

Endogenous timing in pollution control: Stackelberg versus Cournot-Nash equilibria

Mélanie HEUGUES

*LERNA, Toulouse School of Economics
and LAMETA, Montpellier*

Séminaire [Eco-Opti]

Paris-Nanterre, le 4 février 2010

Motivation

- On the order of move, both alternatives are:
 - A simultaneous one: Cournot-Nash concept;
 - A sequential one under perfect information: Stackelberg concept (first player = leader/ second player = follower).
- An order of move not assumed exogenously:
 - Agents must have the opportunity to choose.
- Intuitions:
 - Results rely on the type of interactions between agents;

Framework

- The problem of climate change:
 - The implementation of environmental policies
 - A global character: the necessity of a coordinated action
 - A strategic dimension: utilities/payoffs are interdependent
 - Main challenges linked to the control of greenhouse gases:
 - The public good character of the environment
 - A non-cooperative framework
 - The sovereignty of States and the lack of supranational authority
- ➡ **Objective:** to see if a country or a group of countries can emerge as a leader in implementing its environmental policy.
- An illustrative case: the Copenhagen climate change conference

Literature (1/2)

- *The Global Emission Game* (Finus, 2001)
 - Hoel (1991, 1992); Carraro and Siniscalco (1993);
 - Barrett (1994); Diamantoudi and Sartzetakis (2006);
 - Finus (2001).
- The underlying game exists with both sequences of move:
 - A simultaneous move game;
 - A sequential move game under perfect information (the cooperating countries behaving as a leader).

 The sequence of move is always an exogenous assumption.

Literature (2/2)

- Strategic interactions:
 - The traditional assumption:
 - Leakage are negative;
 - Strategies are assumed substitutable between countries;
 - A less usual assumption:
 - Leakage can also be positive;
 - The existence of complementarities between countries' strategies;
 - Theoretical and empirical evidences: Quirion and Monjon (2009), Fredriksson and Millimet (2004a, 2004b), Copeland and Taylor (2005).

Outline

1. The 2-country global emission game
2. The extended 2-country global emission game
3. Existence of equilibria in the second stage game
4. Results: Subgame-Perfect Equilibria (SPE) of the extended game
5. Environmental impact of the SPE

1. The 2-country global emission game

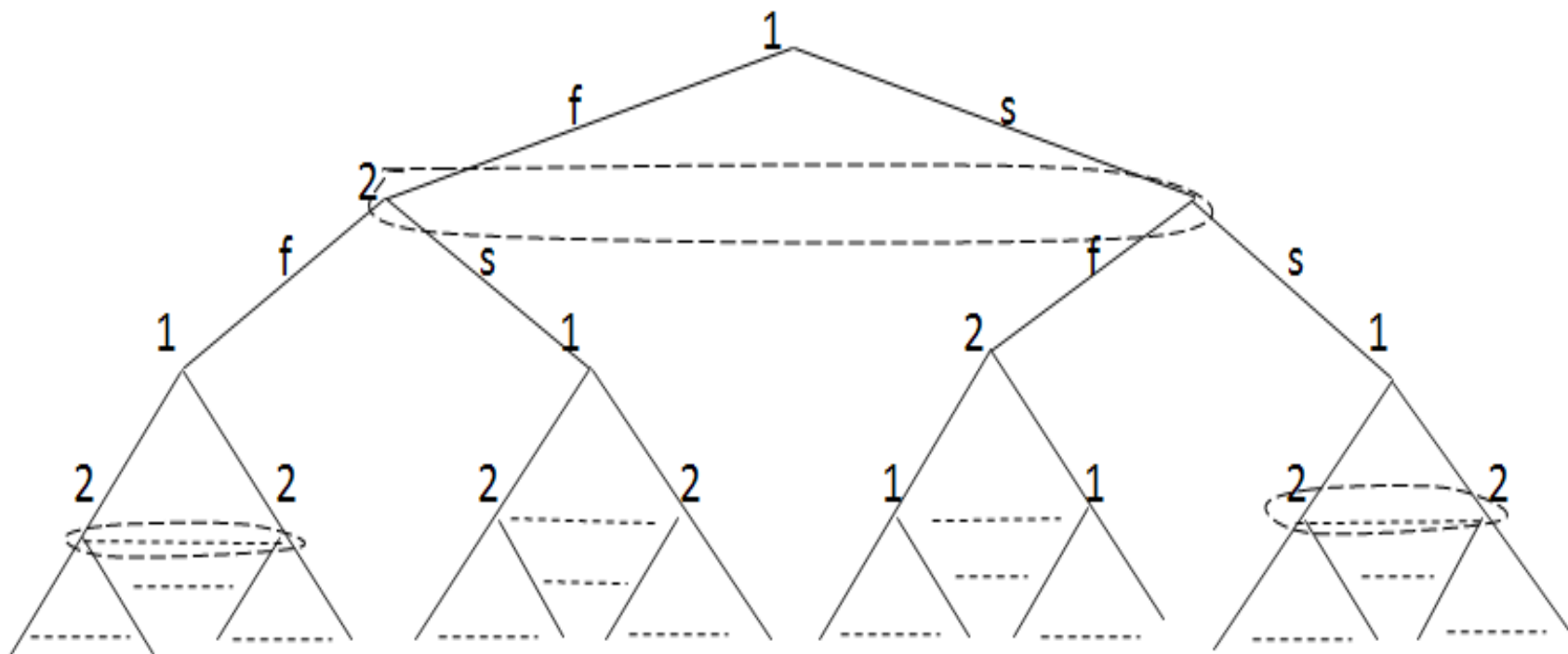
- Two asymmetric countries with payoff functions:
 - Country 1: $f_1(x, y) = B_1(x) - D_1(x + y)$
 - Country 2: $f_2(x, y) = B_2(y) - D_2(x + y)$
- Assumption:
 - $B_i(\cdot)$ and $D_i(\cdot)$, $i = 1, 2$: twice continuously differentiable and non decreasing;
 - $X_i = [0, K_i]$: compact interval of the real.
- The sign of the cross partial derivatives of the payoff functions:
 - $\partial^2 f_i(x, y) / \partial x \partial y < 0, \forall i = 1, 2$: the objective reflects strategic substitutes (natural assumption in the literature on international cooperation);
 - $\partial^2 f_i(x, y) / \partial x \partial y \geq 0, \forall i = 1, 2$: the objective reflects strategic complementarities.

2. The extended 2-country global emission game (1/3)

- Timing: A 2-country, 2-step game
 - **Step 1:** countries choose simultaneously and independently the date (first period or second period) they want to play in the global emission game;
 - **Step 2:** countries choose their emission level maximising their own payoff and given the sequence of move as announced.
- Time does not matter when determining payoffs:
There is no discounting.
- Notations:
 - C^N : set of Cournot-Nash equilibrium strategies
 - S_i : set of Stackelberg equilibrium strategies with country i as leader
 - E : set of Subgame-Perfect Equilibria (SPE) of the extended game.

2. The extended 2-country global emission game (2/3)

- The extensive form of the two-country extended game:



2. The extended 2-country global emission game (3/3)

- The strategic form of the game:

		Country 2	
		First (f)	Second (s)
Country 1	First (f)	f_1^{CN}, f_2^{CN}	f_1^L, f_2^F
	Second (s)	f_1^F, f_2^L	f_1^{CN}, f_2^{CN}

- Assumptions:
 - Each country always prefers to be a leader than a simultaneous player at equilibrium: $f_i^L > f_i^{CN}$
 - Only equilibria in pure strategies are considered.

3. Existence of equilibria in the second stage game

- Existence of Cournot-Nash equilibria in the simultaneous game:

Proposition 1: $D_i(\cdot)$, ($i = 1, 2$) strictly convex, $\forall x, y \geq 0$ and $\exists \bar{Z}_i \in [0, K_i]$ such that $B_i(Z) - D_i(Z) \leq B_i(\bar{Z}_i) - D_i(\bar{Z}_i)$, $\forall Z$ ($i = 1, 2$), Then countries' strategies are substitutable and C^N is non empty.

Proposition 2: $B_i(\cdot)$ strictly concave and $D_i(\cdot)$ with strictly decreasing differences in (x, y) , ($i = 1, 2$), then countries' strategies are complementary and C^N is non empty.

- Existence of Stackelberg equilibria in the sequential game with perfect information:

- Hellwig and Leininger (1987):

For compact strategy sets and continuous payoff functions, Stackelberg equilibria always exist and S_1 and S_2 are non empty.

4. Results: the SPE of the extended game

- Result 1:

When both countries' strategies are substitutable with no emission level being 0, then:

$$E = \{(f, f), C^N\}$$

- Result 2:

When both countries' strategies are complementary, then:

$$E = \{(f, s), S_1\} \cup \{(s, f), S_2\}$$

- Result 3:

If country 1's strategies are substitutable and country 2's strategies are complementary and if there exists an interior Cournot-Nash equilibrium, then:

$$E = \{(f, s), S_1\}$$

5. Environmental impact of the SPE

- A priori indeterminate under Result 1:
 - The Cournot-Nash equilibrium is the best option from a global point of view only under **weak** substitutability;
 - But not when strategies are **strongly** substitutable.
- The SPE lead to the lowest aggregated emission level with regard to the alternative not chosen under Result 2 and 3:
 - Both countries reduce their emissions with regard to the simultaneous move game;
 - The Stackelberg equilibrium is always the best option.

Conclusions

- The results:
 - Confirm the widespread perception that the sequential move game is unsuitable under the natural assumptions of the global emission game;
 - Establish the conditions under which a leader emerges endogenously;
 - Conclude on the environmental impact of each issue
- Minimal assumptions
- Empirical evidences:
 - The complementary nature of the interaction between States:
 - What is the nature of interactions between the biggest polluting countries?