International cooperation on climate change and innovation:
R&D spillovers, absorptive capacity and abatement policy

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BACKGROUND

- Environmental R&D = R&D leading to improved technology that decreases the marginal cost of emission reductions.
  - i.e. technology advances that either increase energy efficiency, or reduce costs of non-carbon energy, or reduce costs of carbon capture and storage (CCS) (Golombek and Hoel, 2011).
- Why combining cooperation in R&D with cooperation in emissions?
  - Even with no explicit agreement on emissions, a technology agreement leading to increased R&D, and thus to lower abatement costs, might result in a reduction in emissions. This may in turn reinforce the likelihood of an agreement (e.g. Montreal Protocol). (Barrett, 2003, 2006; Golombek and Hoel, 2004).

TRADITIONAL FRAMEWORK

- Model with a standard negative climate externality and a positive technology externality:

$$F^i = R(e_i, x_i, X) - D(e_i + E_{-i}) - G(x_i)$$

  - e_i and E_{-i} are country i emissions and aggregated emissions of all the others
  - x_i is country i R&D and X actual R&D carried out by the others

- Cost of reducing emissions is considered through the income function $R(e_i, x_i, X)$ (Popp, 2004, 2006; Golombek and Hoel, 2011).

- Technology diffusion:

$$\phi_i = x_i + \beta X$$

  - With β the spillover parameter and $0 < \beta < 1$.

R&D SPILLOVERS & ABSORPTIVE CAPACITY

- Empirical literature on the existence of international spillovers
  - in general purpose R&D (Griffith, Redding, Van Reenen, 2003)
  - and in energy technologies in particular (Verdolini and Galeotti, 2011).

- Even if spillovers are often model like above in a wide range of theoretical and empirical studies, it’s not obvious that this is the best way to model technology spillovers between firms and countries (Golombek and Hoel, 2004).

- Cohen and Levinthal (1989): the ability of a firm to learn from other firms may depend on its own R&D effort.
  - Griffith et al. (2004) provides empirical evidences on the two roles of R&D. The first is to stimulate innovation and the second is in facilitating the imitation of others’ discoveries (absorptive capacity), thus enhancing technology transfer.
  - Leary and Neary (2007) provides a general model of absorptive capacity.

GOAL OF THE PAPER

1) To combine cooperation in R&D with cooperation in emissions exploiting the concept of absorptive capacity as modeled by Leary and Neary (2007)

2) To generalize some existing results of the literature through the consideration of general welfare functions

As a whole, we want to study in which respect cooperation in R&D should be an alternative or a prerequisite to the cooperation in emissions.

OUTLINE

1) The concept of absorptive capacity

2) The model

3) Preliminary results

- The non-cooperative case
- The cooperation in R&D alone
- On the incentive to cooperate in emissions

ABSORPTIVE CAPACITY: DEFINITION

- Own investment in R&D is needed to transform actual others' R&D X into usable others' R&D y (Cohen and Levinthal, 1989):

$$\phi_i = x_i + \beta y \text{ with } 0 < \beta < 1 \text{ and } y = y(x_i, X)$$

  - y usable others' R&D
  - y/X country absorptive capacity

- Underlying assumptions
  - $y \leq X$: usable others' R&D cannot exceed actual others' R&D;
  - $y_x \geq 0$: usable others' R&D is increasing in own R&D;
  - $0 \leq y_X \leq 1$ (Depends on how difficult it is to absorb others' R&D; the higher the difficulty, the lower is y_X).

ABSORPTIVE CAPACITY: IMPLICATIONS

- Notations:
  - $\tilde{\theta}$ is the effectiveness of own R&D on marginal abatement cost under the concept of absorptive capacity
  - $\tilde{\beta}$ is the effective spillover parameter under absorptive capacity

<u>Result (Leary and Neary, 2007):</u>

- $\tilde{\theta} \geq \theta$ with a strict inequality for $\beta y_x > 0$
- and $\tilde{\beta} \leq \beta$ with a strict inequality for either $y_X < 1$ or $y_x > 0$.

THEORETICAL MODEL

- 2-stage game with n symmetric countries
  - Stage 1: countries determine their individual R&D expenditure
  - Stage 2: countries determine their emission level

- Individual welfare function

$$F^i = R(e_i, x_i, y) - D(e_i + E_{-i}) - G(x_i)$$

with $y = y(x_i, X)$

- Main notations:
  - e_i and E_{-i} are country i emissions and aggregated emissions of all the others
  - x_i and y are country i R&D and usable other countries' R&D
  - X is the actual R&D carried out by the others
  - Usable others' R&D y depends on country i own investment x_i and on the actual level of R&D carried out by the other countries: $y = y(x_i, X)$.

UNDERLYING ASSUMPTIONS

- $R(e_i, x_i, y)$ is strictly concave and differentiable
  - Note $e^b(x_i, y)$ the Business-as-Usual emission level
  - For $e_i < e^b\ (x_i, y)$, we have
    - $R(e_i, x_i, y)$ is increasing in all its arguments
    - $R_{ex} < 0$ and $R_{ey} < 0$ and such that $R_{ex} < R_{ey} < 0$
- $D(e_i + E_{-i})$ is differentiable and can be either strictly concave or strictly convex
  - If $D(e_i + E_{-i})$ is strictly concave, we need in more $R_{ee} < 2D''$ to ensure uniqueness in the second stage game
- $G(\cdot)$ the cost of investing in R&D is increasing and convex in the level of R&D

NON-COOPERATIVE CASE (1/4)

- The game is solved by backward induction
- Existence, uniqueness and characterization

<u>Proposition 0:</u>

Under the assumption above, the two-stage game has a unique symmetric subgame perfect equilibrium.

<u>Proposition 1</u>

Irrespective of the nature of the interaction between countries in the emission game, the equilibrium emission level is decreasing in R&D levels x_i and y and in the effective spillover parameter $\tilde{\beta}$.

NON-COOPERATIVE CASE (2/4)

Proposition 2:

In a symmetric equilibrium, the strategic effect of an increase in the R&D of one country on its own welfare is positive if and only if the effective spillover parameter is more than a minimum threshold $\bar{\beta}$.

$$\frac{dF^i}{dx_i} = \frac{\partial F^i}{\partial x_i} + (n-1)F_j^i \frac{de_j}{dx_i} > 0 \text{ if and only if } \tilde{\beta} > \bar{\beta}.$$

- $\bar{\beta}$ is positive if and only if the strategies in the second-stage game are strategic substitutes.

NON-COOPERATIVE CASE (3/4)

<u>Proposition 3:</u>

i) If strategies in emissions are complementary, any increase in a country's R&D expenditures leads to a decrease in the others' individual emission level;

ii) If strategies in emissions are substitutable, an increase in a country's R&D expenditures leads to a decrease in the others' individual emission level if and only if the effective spillover parameter is higher than $\bar{\beta}$.

$$\frac{de_j}{dx_i} = \frac{F_{ii}[\tilde{\beta} - \bar{\beta}]\theta}{\left(F_{ii} - F_{ij}\right)[F_{ii} + (n-1)F_{ij}]}$$

If strategies in emissions are substitutable, $\frac{de_j}{dx_i} < 0$ if and only if $\tilde{\beta} > \bar{\beta}$.

NON-COOPERATIVE CASE (4/4)

- Two-stage game versus one-stage game (digression)
  - One-stage game = simultaneous choice of R&D and emissions: no strategic interaction
  - Two-stage game = sequential choice: strategic interaction

<u>Proposition 4:</u>

With no R&D cooperation, R&D is higher and emissions are lower with strategic behavior than without, if and only if the spillover parameter $\tilde{\beta}$ is more than the threshold level $\bar{\beta}$. If $\tilde{\beta}$ is lower than $\bar{\beta}$, R&D is lower and emissions are higher with strategic behavior than without.

- Generalization of a result by Golombek and Hoel (2004)

INTERNATIONAL COOPERATION IN R&D (1/2)

- Cooperation in R&D
  - Countries cooperate in R&D, though they continue to choose non-cooperatively their emission levels in the second stage game.
  - The cooperative level of R&D is then chosen to maximize the aggregated welfare of all countries, first without affecting the value of the spillover parameter $\tilde{\beta}$.

- Cooperation in R&D with information sharing
  - If cooperation involves information sharing, it's likely to involve an increase in $\tilde{\beta}$, thus increasing the presumption that cooperation in R&D will increase welfare.

INTERNATIONAL COOPERATION IN R&D (2/2)

	No cooperation in R&D	Cooperation in R&D
One-stage game (No strategic interaction)	e^{NC}, x^{NC}	e^{C}, x^{C}
Two-stage game (Strategic interaction)	$\hat{e}^{NC}, \hat{x}^{NC}$	$\hat{e}^{C}, \hat{x}^{C}$

- Ranking in the incentives to engage in R&D
  - With no strategic interaction (second row), $x^C > x^{NC}$ (and $e^C < e^{NC}$) as soon as the spillover parameter is strictly positive
  - With strategic interaction (third row), the result can be reversed depending on the magnitude of the effective spillover parameter $\tilde{\beta}$.
  - Proposition 4 (above) already compares outcomes in the case of no cooperation in R&D (second column)
  - How evolve R&D and emissions when countries cooperate in R&D but behave strategically? (third column)

COOPERATION IN R&D AND IN EMISSIONS

- Implications of the cooperation in R&D on the incentives to cooperate in emissions
  - Having examined how different assumptions about strategic behavior and R&D cooperation affect emissions and R&D, we turn to evaluate the different equilibria with and without cooperation in emissions.
  - Cooperation in R&D alone can lead to reduced emissions level if $\tilde{\beta} > \bar{\beta}$.
  - If cooperation in R&D (through information sharing for example) is coupled with cooperation in emissions, then we should observe more abatement from all the parties.

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