Emission Trading and Foreign Direct Investments: an evolutionary theoretical model

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Motivations

- Increasing attention devoted to Emission Trading Schemes (ETS) both in the EU and outside (California, Quebec, China etc...)
- Growing literature on the possible impact of ETS on competitiveness and on low-carbon innovation (Martin et al., 2015)
- Empirical studies find mixed evidence: no consensus on the effects of the ETS

Literature

- Qualitative analyses based on managerial interviews (see, e.g., Hoffmann, 2007; Aghion et al., 2009; Rogge et al., 2011)
- Quantitative analyses based on econometric models (see, e.g., Ellerman and Buchner, 2008; Borghesi et al., 2015; Calel and Dechezlepretre, 2016)
- Theoretical models (see, e.g., Borghesi, 2011; Moreno-Bromberg and Taschini, 2011; Perino and Requate, 2012; Antoci et al., 2014; Kollenberg and Taschini, 2016)
- Grubb et al. (2012): "findings are at odds with classical theory but consistent with theories of behavioral economics"

What's new

- Evolutionary game dynamics (see, e.g., Friedman, 1991; Sethi and Somanathan, 1996; Hofbauer and Sigmund, 2003)
- Bounded rationality and imitative behaviors (see, e.g., Hofbauer and Weibull, 1996; Schlag, 1998)
- Study the functioning of ETS and its impact on the diffusion of eco-innovation in the presence of 3 interacting populations of firms that act strategically
- Analysis of the market dynamics: in and out

The model

- Three populations of firms that produce a homogeneous good
- NP firms use not polluting technology and so need no permits: "clean"
- P firms use polluting technology "at home" (in a ETS country) and buy permits: dirty but "compliant"
- PP firms use polluting technology but move their production to some other non-ETS country: "carbon-leakage"
- $m, n, s \in R_+$ are the number, respectively, of NP, P, PP firms

Payoff functions

$$\pi_{NP} = p \cdot q_{NP} - C^F_{NP} - \frac{C^V_{NP}}{2} \cdot q^2_{NP}$$

$$\pi_P = p \cdot q_P - C^F_P - \frac{C^V_P}{2} \cdot q^2_P - q_P \cdot p_T$$

$$\pi_{PP} = p \cdot q_{PP} - C^F_P - \frac{C^V_P}{2} \cdot q^2_{PP} - T$$

where p is the unit price of the good, q_i represent the quantities, $C^F_i, C^V_i > 0$ are respectively the fixed and variable costs, p_T is the unit price of the tradable permit, $i = NP, P, PP$; assume $C^F_{NP} > C^F_P$; T is the fixed cost of delocalization (moving abroad).

Prices

Demand function:

$$p = \overline{p} - a(m \cdot q_{NP} + n \cdot q_P + s \cdot q_{PP})$$

Permits price:

$$p_T = \overline{p_T} + d \cdot q_P \cdot n$$

where $\overline{p}, a, d > 0$ and $\overline{p_T} \geq 0$.
Each firm maximizes its own profit π_i taking p and p_T as exogenously given, i.e. perfect competition both on the output and on the permits market.

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Dynamic System

The inter-temporal evolution of m, n and s is:

$$\dot{m} = m \cdot \pi_{NP}(m, n, s)$$
$$\dot{n} = n \cdot \pi_{P}(m, n, s)$$
$$\dot{s} = s \cdot \pi_{PP}(m, n, s)$$

It follows that:

$$\pi_{NP} \gtrless 0 \Rightarrow \dot{m} \gtrless 0$$
$$\pi_{P} \gtrless 0 \Rightarrow \dot{n} \gtrless 0$$
$$\pi_{PP} \gtrless 0 \Rightarrow \dot{s} \gtrless 0$$

If a strategy is profitable (unprofitable) new firms enter (exit) the market, which increases (decreases) the market size. The market has no entry/exit barriers.

Strategic framework

From the dynamic system it descends that the growth rates satisfy the following proprieties:

$$\pi_{NP}(m,n,s) \gtrless \pi_{P}(m,n,s) \gtrless 0 \Rightarrow \dot{m}/m \gtrless \dot{n}/n$$
$$\pi_{NP}(m,n,s) \gtrless \pi_{PP}(m,n,s) \gtrless 0 \Rightarrow \dot{m}/m \gtrless \dot{s}/s$$
$$\pi_{P}(m,n,s) \gtrless \pi_{PP}(m,n,s) \gtrless 0 \Rightarrow \dot{n}/n \gtrless \dot{s}/s$$

The best (worst) strategy spreads (disappears) more rapidly than the alternative strategy.

F.O.C.

The first order conditions are:

$$\frac{\partial \pi_P}{\partial q_P} = p - C_P^V \cdot q_P - p_T \leq 0, \quad \frac{\partial \pi_P}{\partial q_P} \cdot q_P = 0$$
$$\frac{\partial \pi_{PP}}{\partial q_{PP}} = p - C_P^V \cdot q_{PP} \leq 0, \quad \frac{\partial \pi_{PP}}{\partial q_{PP}} \cdot q_{PP} = 0$$
$$\frac{\partial \pi_{NP}}{\partial q_{NP}} = p - C_{NP}^V \cdot q_{NP} \leq 0, \quad \frac{\partial \pi_{NP}}{\partial q_{NP}} \cdot q_{NP} = 0$$

The following equation represents the plane that separates the region in which $q_P > 0$ (above) from that in which $q_P = 0$ (below):

$$\frac{C_P^V}{C_{NP}^V} m + s = \frac{C_P^V}{a\overline{p_T}} \left(\overline{p} - \overline{p_T}\right)$$

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Equilibrium values

Above the plane, that is when $q_P > 0$, the optimal values are:

$$q_P^* = \frac{\overline{p} - a\frac{\overline{p_T}}{C_P^V}\left(\frac{C_P^V}{C_{NP}^V}m + s\right) - \overline{p_T}}{C_P^V + (a+d)\cdot n + a\left(\frac{C_P^V}{C_{NP}^V}m + s\right)\left(1 + \frac{d}{C_P^V}n\right)}$$

$$q_{PP}^* = \frac{\overline{p_T}}{C_P^V} + \left(1 + \frac{d}{C_P^V}n\right)q_P^*$$

$$q_{NP}^* = \frac{C_P^V}{C_{NP}^V}\cdot q_{PP}^*$$

Below the plane, that is when $q_P = 0$, the optimal values are:

$$q_{PP}^* = \frac{\overline{p}}{a\left(\frac{C_P^V}{C_{NP}^V}m + s\right) + C_P^V}$$

$$q_{NP}^* = \frac{C_P^V}{C_{NP}^V}\cdot q_{PP}^*$$

Coexistence

Stationary states, in which all three types of firms (NP, P, and PP) coexist, exist if and only if:

$$T = C_{NP}^{F} \frac{C_{NP}^{V}}{C_{P}^{V}} - C_{P}^{F}$$

Therefore, generically, there will be only equilibria in which no more than two types of firms coexist. Only equilibria in which "clean" (NP) and dirty but "compliant" (P) firms coexist, or in which "compliant" (P) and "carbon leakage" (PP) firms coexist:

- without "carbon leakage" firms $(m, n, 0)$
- without "clean" firms $(0, n, s)$

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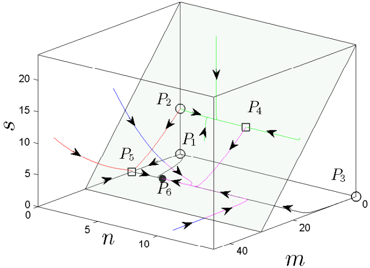
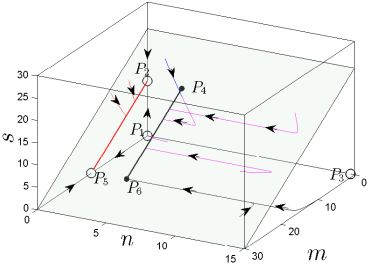
Phase plane



(a) Without carbon leakage firms

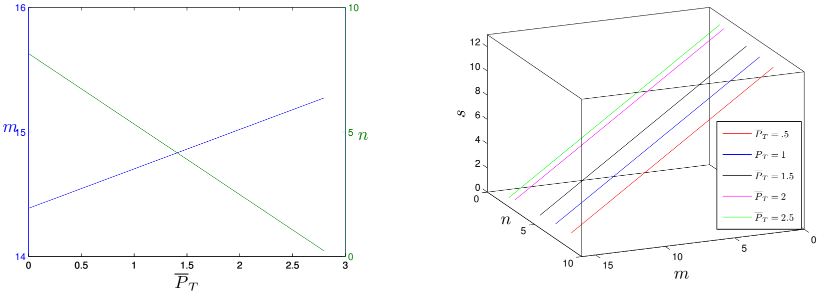


(b) Coexistence

Legend: • attractors, ○ repellors, □ saddle points

$P_1 = (0, 0, 0)$, $P_2 = (0, 0, s)$, $P_3 = (0, n, 0)$, $P_4 = (0, n, s)$,
$P_5 = (m, 0, 0)$, $P_6 = (m, n, 0)$.

Intercept of permit demand function



(a) Without carbon leakage firms **(b)** Coexistence

Conclusions I

- Simple dynamic evolutionary model that can describe the behaviour of different kinds of firms characterized by bounded rationality and imitative behaviours in a competitive and contestable market.
- Similar to a biological competition model (different species compete for a common resource): all firms are in competition among themselves as new entries (no matter whether NP, P or PP) lower the price of the homogeneous good. Moreover, an increase in n (number P-firms), increases PT thus damaging the existing P-firms (it makes strategy P less convenient).

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Conclusions II

- Numerical simulations show that coexistence between firms is possible (but very unlikely). If this is the case, infinite attractors (indeterminacy)
- There exists an attractive equilibrium in which carbon leakage firms exit the market (no ETS-induced FDI)
- ETS can have positive effect on ecoinnovation: a rise in the permits' price floor tends to increase (decrease) the number of clean (dirty/compliant) firms thus shifting the composition of the market

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THANKS

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