Emission permits and ECSR practice in an evolutionary duopoly

Gianluca IANNUCCI and Alessandro TAMPIERI

Department of Economics and Management, University of Florence

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What is an Emission Trading System (ETS)

- A scheme that allocates emissions' rights to firms.
- Distribution of rights:
  - for free (grandfathering),
  - through an auction mechanism.
- Market-based instrument that gives an incentive to improve the internal emission abatement.
- Real world examples:
  - EU ETS (since 2005),
  - Regional Greenhouse Gas Initiative (since 2009),
  - California Cap and Trade (since 2013),
  - China National ETS (since 2021).

Environmental Corporate Social Responsibility (ECSR)

- ECSR firms commit to a behavior that takes into account:
  - profit,
  - consumers,
  - environment.
- Economic theory suggests strategic reasons (Kopel and Brand 2012 (EconMod), Lambertini and Tampieri 2015 (EconMod), *inter alia*). Why?:
  - socially and environmentally concerned consumers would buy from CSR firms;
  - a ECSR firm may force the rivals to reduce their production;
  - interaction with emission abatement policies.

Interaction between ETS and ECSR

- Pros:
  - Lee (2011, EnerPol): potential cost savings in industries.
  - Gasbarro, Rizzi, Frey (2013, EurMangJ): sinergies between environmental management practices and compliance in the Italian pulp industry to EU ETS scheme.
  - Kong, Liu, Dai (2014, CSREM): the introduction of a carbon emission right trading policy in China boosts the environmental protection initiatives among firms.
- Cons:
  - Doda, Gennaioli, Goundson, Grover, Sullivan (2015, CSREM): no impact on carbon emissions under the EU trading scheme.
  - Martin, Muûls, Wagner (2016, REEP): inconclusive on the effects of the ETS on the diffusion of clean technologies.

Interaction between ETS and ECSR

- The ambiguous evidence calls for a theoretical explanation.
- Do markets regulated under ETS favor initiatives of environmental practice or not?
- The answer to this question is the scope of the present analysis.

Why evolutionary game theory (EGT)

- Evolutionary game theory allows to endogenize the firms' strategy choice in a mixed strategy context showing all the possible industry configurations that may arise.
- The dynamic framework helps to compare an industry regulated by an ETS with another one unconstrained.
- Applications of EGT to ETS games: Antoci, Borghesi, Iannucci, Russu (2019, Meca), Antoci, Borghesi, Iannucci, Sodini (2021, EneEco).
- Applications of EGT to CSR games: Kopel and Lamantia (2018, JEDC), Iannucci and Tampieri (2023, EneEco).

The model

- $N \geqslant 2$ Nash players firms competing in quantities.
- Unique homogeneous good.
- Two types of firms:
  - $m \geqslant 0$ environmentally and socially concerned (ECSR), subscript e,
  - $N - m \geqslant 0$ profit seeking (PS), subscript p.
- Choice variables: quantities (q) and abatement investments (z), and $q - z$ represents emissions.

Maximization problems

$$\max_{\substack{q_e, z_e \geqslant 0 \\ (q_e - z_e) \geqslant 0}} O_e = \underbrace{(p-c)q_e - \frac{1}{2}z_e^2}_{\pi_e} + \beta CS - (q_e - z_e)\delta$$

$$\max_{\substack{q_p, z_p \geqslant 0 \\ (q_p - z_p) \geqslant 0}} \pi_p = (p-c)q_p - \frac{1}{2}z_p^2$$

where:

$$p = \gamma - \sum_{i=1}^{m} q_i - \sum_{j=1}^{N-m} q_j \quad \text{and} \quad CS = \frac{1}{2}\left(\sum_{i=1}^{m} q_i + \sum_{j=1}^{N-m} q_j\right)^2$$

$\gamma > 0$ is the output market reservation price, $\beta \in [0, 1]$ is the social concern, $\delta \in [0, 1]$ is the environmental concern.

Optimal values

Assuming $\gamma - c = \mu$, we have:

Proposition

$$q_e^* = \frac{\mu - \delta + (\beta - \delta)(N - m)}{N - \beta m + 1}$$

$$z_e^* = \delta$$

$$q_p^* = \frac{\mu - (\beta - \delta)m}{N - \beta m + 1}$$

$$z_p^* = 0$$

Corollary

The condition $\delta \in (\underline{\delta}, \overline{\delta})$ is such that $q_p^* > 0$ and $q_e^* - z_e^* > 0$ for each market composition.

Evolutionary setting

- A very large population of firms composed of both ECSR and PS. At each instant, two firms are randomly selected to play the one-shot game described above (Droste, Hommes, and Tuinstra 2002 (GEB)).
- The payoff of adopting a strategy is a function of the probability of encountering.
- $x \in [0, 1]$ is the share of ECSR firms on the market, and $1 - x$ the share of PS firms.

Expected profits

- Optimal profits:

$$\pi_e^* = q_p^* q_e^* - \frac{\delta^2}{2}$$
$$\pi_p^* = (q_p^*)^2$$

- The expected profit of the ECSR firm is:

$$\mathbb{E}(\pi_e^*(x)) = x\pi_{ee}^* + (1-x)\pi_{ep}^*$$

- The expected profit of the PS firm is:

$$\mathbb{E}(\pi_p^*(x)) = x\pi_{pe}^* + (1-x)\pi_{pp}^*$$

Selection process

- Replicator dynamics:

$$\dot{x} = x(1-x)\left[\mathbb{E}(\pi_e^*(x)) - \mathbb{E}(\pi_p^*(x))\right]$$

- Three types of steady states:
  - $x = 0$, all firms are PS,
  - $x = 1$, all firms are ECSR,
  - $x \in (0,1)$, coexistence if stable, segmentation if unstable.
- Only stable steady states are Nash equilibria.
- Denoting x^* as a stable steady state, the corner ones $x^* \in \{0,1\}$ are pure Nash equilibria, while the inner $x^* \in (0,1)$ is a mixed-strategy Nash equilibrium (Bomze 1986, IJGT).

Industry configurations

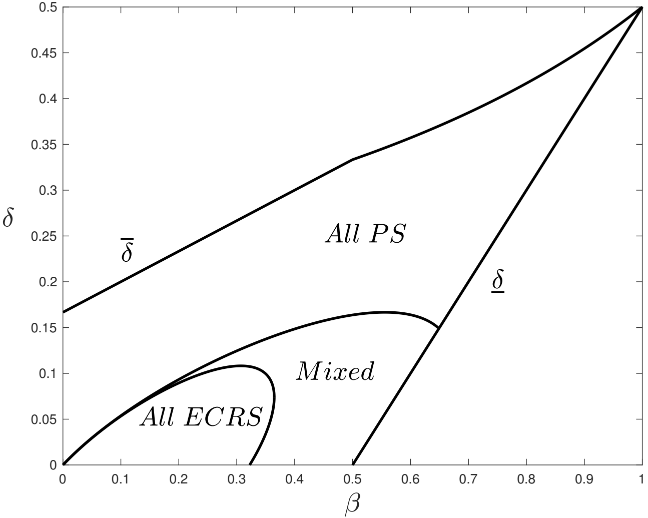
Proposition

Three industry configurations may arise:

- *All firms are ECSR, for* $\delta \in (\widehat{\delta}, \delta_4)$.
- *All firms are PS, for* $\delta \in (\delta_2, \overline{\delta})$.
- *Mixed duopoly, for* $\delta \in \left((\underline{\delta}, \delta_2) \backslash (\widehat{\delta}, \delta_4) \right)$.

Where δ_2 *is one of the solution of the equation* $\pi^*_{ep} - \pi^*_{pp} = 0$ *and* $\delta_{3,4}$ *are the solution of the equation* $\pi^*_{ee} - \pi^*_{pe} = 0$, *while* $\widehat{\delta} = \max\{\underline{\delta}, \delta_3\}$.

Dynamic regimes



The model with ETS

Firms have to pay an allowance ($a > 0$) for emitting. Two stages game solved in backward induction.

1) The permit's price is market clearing and the government set the cap of the ETS ($\overline{E}$):

$$(q_e^{*\ ets} - z_e^{*\ ets})m + (q_p^{*\ ets} - z_p^{*\ ets})(N - m) = \overline{E}$$

2) Firms maximization problems:

$$\max_{\substack{q_e^{ets}, z_e^{ets} \geqslant 0 \\ (q_e^{ets} - z_e^{ets}) \geqslant 0}} O_e^{ets} = (p^{ets} - c)q_e^{ets} - \frac{1}{2}(z_e^{ets})^2 + \beta CS^{ets} - (q_e^{ets} - z_e^{ets})(\delta + a)$$

$$\max_{\substack{q_p^{ets}, z_p^{ets} \geqslant 0 \\ (q_p^{ets} - z_p^{ets}) \geqslant 0}} \pi_p^{ets} = (p^{ets} - c)q_p^{ets} - \frac{1}{2}(z_p^{ets})^2 - (q_p^{ets} - z_p^{ets})a$$

Optimal values

Proposition

$$a^* = \frac{N\mu - (N+1)\overline{E} - [(N+2)\delta + (\delta m + \overline{E})\beta]m}{(N - \beta m + 2)N}$$

$$q_e^{*\ ets} = \frac{\mu - \delta - a^* + [(1-a^*)\beta - \delta](N-m)}{N - \beta m + 1}$$

$$z_e^{*\ ets} = \delta + a^*$$

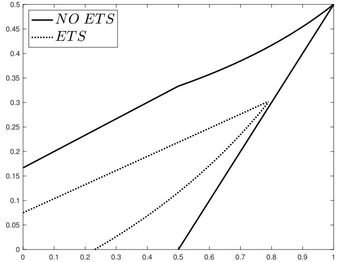
$$q_p^{*\ ets} = \frac{\mu - a - [(1-a)\beta - \delta]m}{N - \beta m + 1}$$

$$z_p^{*\ ets} = a^*$$

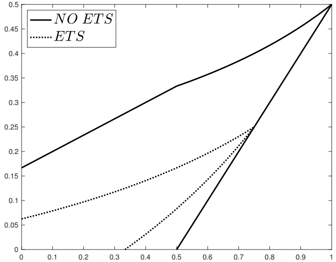
Corollary

The condition $\delta \in (\underline{\delta}^{ets}, \overline{\delta}^{ets})$ guarantees positive emissions and allowance price for each market composition.

Existence regions



(a) $\overline{E} = 0.3$.



(b) $\overline{E} = 0.5$.

Industry configurations

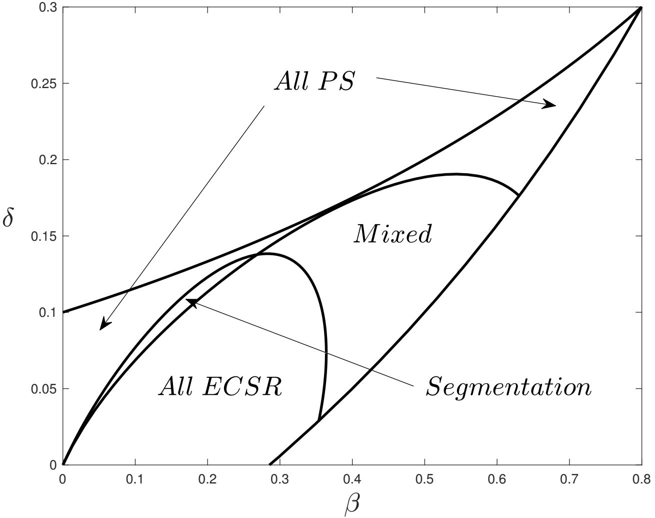
Proposition

Denoting $x^{*\ ets}$ as a stable steady state, four industry configurations may arise:

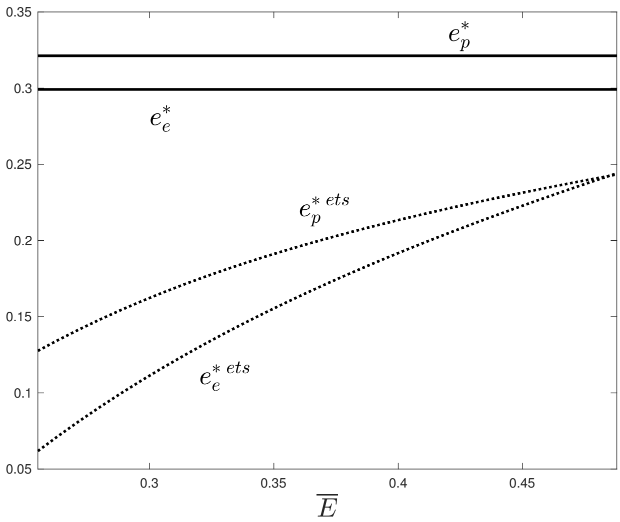
- *All firms are ECSR, for $\delta \in (\widetilde{\delta}_1, \widetilde{\delta}_2)$.*
- *All firms are PS, for $\delta \in (\widetilde{\delta}_3, \overline{\delta})$.*
- *Mixed duopoly, for $\delta \in \left((\widetilde{\delta}_4, \widetilde{\delta}_5)\backslash(\widetilde{\delta}_1, \widetilde{\delta}_2)\right)$.*
- *Segmentation, for $\delta \in (\delta_8, \delta_6)$.*

Where $\widetilde{\delta}_1 = \max\{\underline{\delta}, \delta_7\}$, $\widetilde{\delta}_2 = \min\{\delta_6, \delta_8\}$, $\widetilde{\delta}_3 = \max\{\delta_6, \delta_8\}$, $\widetilde{\delta}_4 = \max\{\underline{\delta}, \delta_5\}$, $\widetilde{\delta}_5 = \min\{\delta_6, \overline{\delta}\}$, $\delta_{5,6}$ are the solution of of the equation $\pi_{ep}^{*\ ets} - \pi_{pp}^{*\ ets} = 0$, while $\delta_{7,8}$ are the solutions of the equation $\pi_{ee}^{*\ ets} - \pi_{pe}^{*\ ets} = 0$.

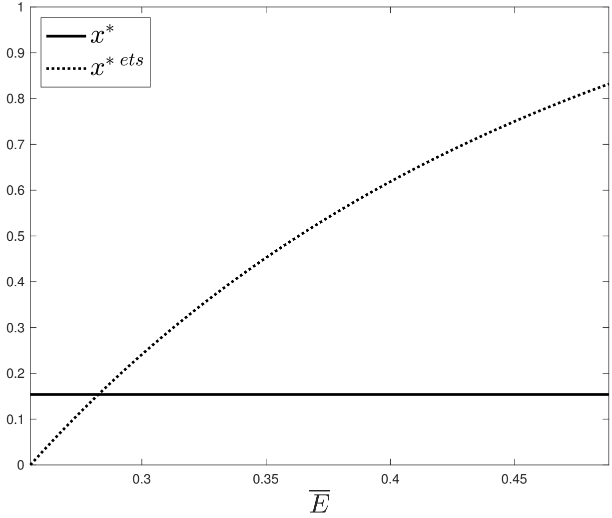
Industry configurations



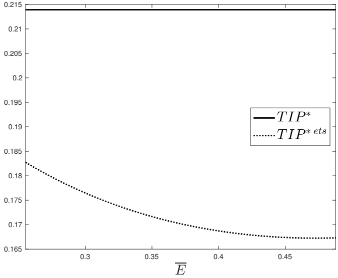
Individual firm emissions at x^* and $x^{*\,ets}$



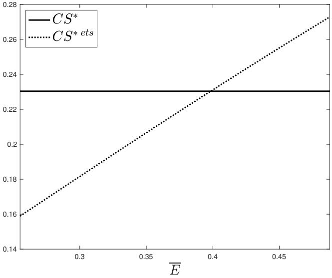
Evolution of ECSR strategy w.r.t. the cap of the ETS



Total Industry Profits and Consumer Surplus

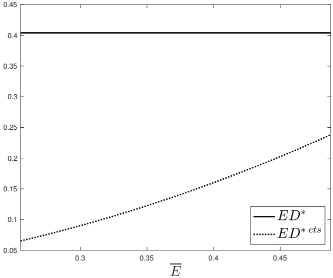


(a) $TIP = [\mathbb{E}(\pi(x))]N$.

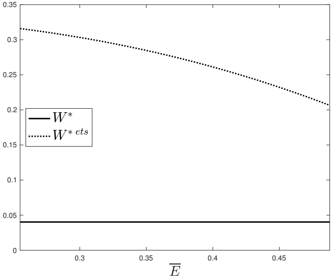


(b) $CS = \frac{1}{2}\left(xNq_e + (1-x)Nq_p\right)^2$.

Environmental Damage and Welfare



(a) $ED = [(q_e - z_e)xN + (q_p - z_p)(1-x)N]^2$.



(b) $W = TIP + CS - ED + PR$,

$PR = [(q_e - z_e)xN + (q_p - z_p)(1-x)N]a$.

Conclusions

- We study the interaction between ECSR practice and ETS policy.
- The introduction of an ETS favors the ECSR strategy reducing the region where all firms are PS.
- The introduction of an ETS may generate market segmentation.
- The stringency of the ETS policy (lower cap) favors the PS strategy.
- The ETS decreases the Total Industry Profits and the Consumer Surplus but by contrast reduces the Environmental Damage and increases the Welfare.

THANK YOU