Commitment to environmental policy under green R&D strategic interaction

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FEEM SEMINAR

Work in progress

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October 17th, 2013

Motivation (I). The complexity of green technologies

- **California's Green Chemistry Regulation** - California Department of Toxic Substances Control (ongoing debate, Spring 2013)
  - reduces use of substances (Chemicals of Concern, COC) that exhibit environmental or toxicological endpoint in the design of products and industrial processes
  - develops a list of Priority Products that contain COCs for which an Alternative Assessment (AA) must be conducted
  - defines compliance: manufacturers must submit an AA with the options to remove the COC from the product, to substitute the COC with a safer alternative, to reformulate the product to avoid the COC or in the case of the COC as a contaminant, to put in place process controls to minimize its presence

Motivation (II). The quality dimension of green technologies

- Importance of the quality dimension of green technologies: depending on the production process, **different types** of green chemistry are **suitable**
  - A green techn firm "*SGS can support companies in achieving compliance with the California Green Chemistry initiative and with other green chemistry regulations through testing articles for CoCs, using a risk-based approach*"
  - A business concerned about the regulation: "*These far reaching regulations will require businesses selling production in California to make major inverstments in compliance and change the way manufacturers look at their supply chain and product design planning*"

Motivation (III). Which regulation?

- Taxes and Standards might be relevant regulatory environmental instruments
  - Taxes intended in general as "**price instruments**" - already in place in USA, France and Denmark (tax on **pesticide containers**); NOx **emission fees** in Sweden
- ...but what about the impact of imperfect competition among technology sellers?

Model overview

- Imperfect competition between 2 green tech firms along 2 dimensions
  - vertical differentiation *à la* Hotelling (short term), horizontal differentiation (long term)
- Polluters' choice:
  - full adoption of the 2 **competing** green tech
  - stick to the old one or switch to one of the 2 green tech: each tech firm is then a **local monopolist**
- Environmental regulation: tax
  - *ex ante*: commitment to the instrument of regulation **and its level**
  - *ex post*: commitment to the instrument, its level being decided **after observing adoption**
- Objective: study the **efficiency** of environmental regulation in such a context (taxing at the marginal damage), but also the extent of **competition** in green tech (pricing and quality investment), as well as **adoption** patterns.

- Under some configuration of the parameters, in the **full adoption case**, when the *ex post* tax is higher than the *ex ante* tax, the most efficient technology has **higher adoption** rate in the economy, **lower price**, **higher quality** as compared to the *ex ante* case **but** the **S**ocial **O**ptimum is **not attained** (prices above the marginal cost and underinvestment).
- ...but this might also happen in the case where there are **two local monopolies**, only if the marginal damage is sufficiently low.

Literature review: Adoption induced by regulation

Parry (1995)

- Parry (1995) focuses on *ex ante* tax regulation in a model where the upstream R&D firm sells the patent to downstream polluting firms.
- R&D is stochastic and there is free entry on both markets. As soon as an innovating firm is successful, it gets a patent and becomes the upstream monopolist (**patent race**). Symmetric downstream firms can adopt the new technology by paying a license fee.
- Result: an environmental tax leads to an **increase** in the license **fee** and a decrease on the number of polluting firms in the downstream market, since the ones with the lowest willingness to pay **exit** (**full adoption** of remaining).

Requate (2005)

- Heterogeneous firms; a monopolist sells a new technology that competes with the old one and provides lower abatement costs
- Results:
  - *Ex-ante:* if the monopolist increases output as the tax T increases, $\min Total\ Social\ Cost$ attained for the second best optimal ex ante tax $= T^{ante} > SD'$= Social Marginal Damage
  - *Ex-post*: $T^{post} = SD'$ **but** $\min Total\ Social\ Cost$ is not attained
    - **Monopolist produces more** under *ex-ante* than under *ex-post* regulation: more adoption

Literature review: Adoption, competition?

David & Desgagné (2005)

- Representative polluting firm that pays for each unit of pollution cleaned
- Cournot eco-industry that charges a price for each unit cleaned
- *Only analyze ex-ante commitment:* under taxes, $T^{ante} > SD'$ due to quantity competition in upstream sector: when the eco-industry is non-competitive the price of abatement goods are larger than marginal costs. If the tax is set equal to marginal damage, the polluters would abate less than optimal
- **Optimal adoption if tax** is **higher than marginal damage**

Other...

Requate & Unold (2003)

- *Regulator anticipates the arrival of new technology:*
  - *Ex-ante commitment:* under taxes Social Optimum **(SO) outcome is attained for some values** of the cost of the less polluting technology but multiple equilibria for intermediary values.
  - *Ex-post regulation:* under taxes the SO outcome is attained.

Dollen & Requate (2008)

- Besides the less polluting technology (a) available at a fixed cost F_a there is an advanced technology b that arrives in the future (Poisson distributed of parameter λ) with a cost of F_b BUT same results as before.
  - Only *ex-post regulation is interesting:* despite the uncertainty about the future, it is sufficient for the regulator to stick to the **pigouvian rule** at every point in time.

On the markets for green technologies

- Three technologies: old technology O, two new technologies A or B
  - A and B innovators sell an abatement technology greener than the existing one; competition in price and quality (...not in locations!)
- Continuum of downstream firms $x \in [0, 1]$, each of which chooses to stay with the old technology O or to adopt A or B
- 2 possible market structures:
  - the market is fully covered by the 2 competing technologies A and B (case i)
  - 2 local monopolies, i.e. in the interior of the interval $[0, 1]$ some firms remain with the old technology O (case ii)

General setting

Assumptions (2)

On abatement

- Installed abatement technology $C_0(e_0)$ where e_0 denotes emissions
- New technologies w/ lower abatement costs $C_i(e_i)$, for $i = A, B$
- The abatement cost functions satisfy $C_i(e_i) > 0$, $-C_i'(e_i) > 0$, and $C_i''(e_i) > 0$
- B is the most efficient technology. For a given emission level e :

$$-C_B'(e) < -C_A'(e) < -C_0'(e)$$

On quality

- When adopting from upstream firm $i \in \{A, B\}$, downstream firms incur in adoption cost $F_i(x, r_i)$ depending on the firm specific parameter x and the quality parameter r_i
  - When adopting technology B the adoption cost decreases for firms closer to 1;when adopting technology A the adoption cost increases for firms closer to 0

$$\partial F^A(x, r_A)/\partial x > 0, \quad \partial F^B(x, r_B)/\partial x < 0.$$
$$\partial^2 F^A(x, r_A)/(\partial x)^2 > 0, \quad \partial^2 F^A(x, r_B)/(\partial x)^2 > 0.$$

- Quality cost for upstream firms: $\Gamma_i(r_i)$ with $\Gamma_i'(r_i) > 0$ and $\Gamma_i''(r_i) \geq 0$; marginal production costs: k_i (with $k_A > k_B$)

General setting

Assumptions (4)

- In the following I focus on the full adoption case
- Total Social Cost

By denoting $\tilde{x}$ as the marginal firm indifferent between technology A and B,total social cost in case i) is given by:

$$\begin{aligned} & TSC(e_A, e_B, \tilde{x}, r_A, r_B) \\ = \; & \tilde{x}[C_A(e_A) + k_A] + [1-\tilde{x}][C_B(e_B) + k_B] \\ & + \int_0^{\tilde{x}} F^A(x, r_A)dx + \int_{\tilde{x}}^1 F^B(x, r_B)dx + SD\left[\tilde{x}e_A + (1-\tilde{x})e_B\right] \\ & + \Gamma(r_A) + \Gamma(r_B), \end{aligned}$$

where $SD\left[\tilde{x}e_A + (1-\tilde{x})e_B\right]$ is the damage caused by overall emissions

- Implementation costs:

$$F_A(x, r_A) = \tau x - \alpha r_A,$$
$$F_B(x, r_B) = \tau(1 - x) - \alpha r_B$$

where τ stands for transportation costs and $\alpha > 0$ is marginal contribution of quality

- Linear social damage $SD : D\left[\tilde{x}e_A + (1 - \tilde{x})e_B\right]$
- Quadratic abatement cost C_i for ex., for technology A: $C_A(e_A) = (A - e_A)^2/2 = C_A$
- Quadratic R&D costs $\Gamma_i(r) = r_i^2/2$

Social optimum

- Under the previous assumptions the social optimum (SO) solution is

$$e_A^{SO} = A - D,$$
$$e_B^{SO} = B - D,$$
$$e^{SO} = A + B - 2D.$$

$$\tilde{x}^{SO} = \frac{1}{2\tau}\left(\tau + p_B - p_A + C_B - C_A - \alpha\left(r_B - r_A\right)\right),$$

where $C_i(e_i)$ is simply denoted by C_i

- Firms then set:

$$p_i^{*SO} = k_i,$$
$$r_i^{*SO} = \tfrac{1}{2}\alpha + \tfrac{\alpha((C_j+k_j)-(C_i+k_i)-D(e_i-e_j))}{2(\tau-\alpha^2)},$$
$$i = A, B \qquad i \neq j.$$

- **Optimal investment on quality increases with** polluting firms **adoption costs** $(C_i + p_i)$ (decreases with $(C_j + p_j)$)

- Evaluating at SO equilibrium values we get

$$\tilde{x}^{*SO} = \frac{1}{2}\left(1 - \frac{k_A - k_B + (A - B)\,D}{\tau - \alpha^2}\right),$$
$$r_A^{*SO} = \alpha \tilde{x}^{*SO} \text{ and } r_B^{*SO} = \alpha\left(1 - \tilde{x}^{*SO}\right).$$

- With perfectly **symmetric** technologies, the indifferent consumer is located at the middle of the segment and the investment level are both equal $\alpha/2$

Ex-ante *versus* ex-post regulation

Ex-ante regulation: T is fixed before stage 1

1. Tech firms set qualities r_i
2. Tech firms set prices p_i
3. Polluting firms position themselves in terms of adoption x^* and choose emissions e_i

Ex-post regulation: T is fixed after firms' strategies and adoption decisions have been taken

Ex-ante 2nd-best policy (1)

- Polluting firm will abate pollution up to $-C_i' = T$

$$C_i = \frac{T^2}{2},$$
$$e_A = A - T, e_B = B - T$$
$$\tilde{x}^* = \frac{1}{2\tau}\left(\tau - p_A + p_B + T\left(e_B - e_A\right) + C_B - C_A + \alpha r_A - \alpha r_B\right)$$

- In the second stage, p_i and p_j are strategic complements:

$$p_i = \frac{\left(\tau + k_i + p_j + \left(T\left(e_j - e_i\right) + C_j - C_i\right) + \alpha\left(r_i - r_j\right)\right)}{2}.$$

In the first stage, r_i and r_j are strategic substitutes:

$$r_i = \alpha\frac{\left(3\tau + \left(T\left(e_j - e_i\right) + C_j - C_i\right) - \left(k_i - k_j\right) - \alpha r_j\right)}{9\tau - \alpha^2}$$

- Evaluating prices and qualities in the previous and solving the two-stage-game for tech firms we get equilibrium values p_i^{ante}, r_i^{ante} and $\tilde{x}^{ante}$
- For the most efficient technology B we have (at the optimal abatement):

$$p_B^{ante} = \tau + \frac{1}{2}\frac{4k_B\left(3\tau-\alpha^2\right)+6\tau k_A+3T\tau(T+2)(A-B)}{9\tau-2\alpha^2},$$

$$r_B^{ante} = \frac{1}{3}\alpha\left(1-\frac{3(k_B-k_A-T(A-B))}{9\tau-2\alpha^2}\right),$$

$$\left(1-\tilde{x}_B^{ante}\right) = \left(\frac{1}{2}+\frac{3(k_B-k_A-(A-B)(T-1)T)}{9\tau-2\alpha^2}\right).$$

- Then evaluating TSC at such equilibrium values and deriving w.r.t. T we get the 2nd-best tax for *ex-ante* regulation T^{ante}
- The **FOC is non linear** in T^{ante} : both $T^{ante} < D$ and $T^{ante} > D$ are possible: imperfect competiton distortion
  - If $A = B$ and $k_A = k_B$, $T^{ante} = D$ *i.e.* social optimal abatement

Ex-ante 2nd-best policy (2)

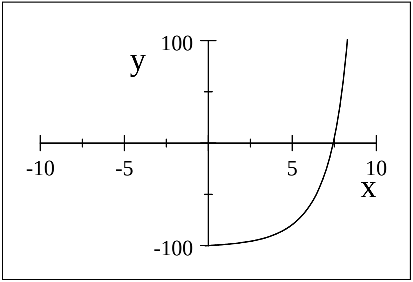
In general terms

$$
\begin{aligned}
T^{ante} \quad = \quad & \underbrace{D'(e)}_{>0} \underbrace{- \frac{1}{e'(T)} \left[(p_A - k_A)x'_A - (p_B - k_B)x'_B\right]}_{>0} \\
& \underbrace{+ \frac{1}{e'(T)} [\int_0^{\widetilde{x}} F_{r_A}(x, r_A)dx - [p_A - k_A]x^A_{r_A}]r'_A}_{?} \\
& \underbrace{+ \int_{\widetilde{x}}^{1} F_{r_B}(1 - x, r_B)dx - [p_B - k_B]x^B_{r_B}]r'_B]}_{?}
\end{aligned}
$$

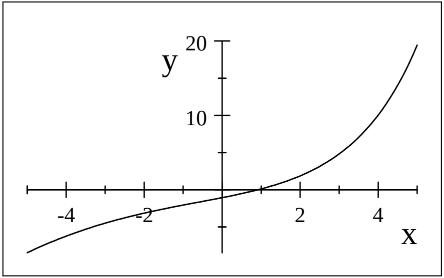
The optimal ex-ante tax is the sum of three terms:

- Marginal damage: positive.
- Second term: positive, since $x_j' > 0$ for $j = A, B$, $e'(T) < 0$, and innovators produce a positive quantity.
- Third term: sign? We have $r_A' > 0; e'(T) < 0$ but the term $\int_0^{\widetilde{x}} F_{r_A}(x, r_A)dx - [p_A - c_A]x_{r_A}^A$ i.e. the difference between the average benefit of increasing r_A and the firm's marginal benefit can be positive or negative
  - similar reasoning for the last term.

- Illustration: numerical simulations for $A - B = 0.5$, $\alpha = \tau = 1, k_A - k_B = 0.5$



$T^{ante} - D$, with $D = 1$



$T^{ante} - D$, with $D = 100$

Comparison with respect to the literature

- Parry (1995): the optimal *ex ante* tax should **always** be **lower** than marginal damage.
  - a low tax **reduces** the **price** and counterbalances the market power of the R&D firm, improving the level of adoption of the most efficient technology.
- Requate (2005): the optimal *ex ante* tax can be **higher** than marginal damage.
  - a higher tax increases the **willingness to pay** of polluters for the more efficient abatement technology.
- Our model: counterbalancing forces...if $T > D$
  - the price of the most efficient technology B increases with the tax
    - *Effect I*: as in Parry this produces a decrease in the level of adoption;
    - *Effect II*: As in Requate, since quality depends positively on the tax, it produces an increase in the level of adoption.
  - Adoption is non linear in the tax rate.

Ex-post 2nd-best policy

- Ex post taxation is such that $T^{post} = D$ so $-C_i' = D$, $C_i = \frac{1}{2}D^2$
- R&D firms' choices will influence the tax
- Solving the two-stages-game we get equilibrium prices and qualities: for technology B

$$\begin{aligned} p_B^{post} &= \tau + \frac{3\tau(k_A - D(B-A)) + 2k_B\left(3\tau - \alpha^2\right)}{9\tau - 2\alpha^2}, \\ r_B^{post} &= \alpha\left(\frac{1}{3} - \frac{(k_B - k_A) + D(A-B)}{(9\tau - 2\alpha^2)}\right), \end{aligned}$$

- The indifferent consumer is:

$$\tilde{x}^{post} = \frac{1}{2}\left(1 - \frac{3((k_A - k_B) + D(A-B))}{9\tau - 2\alpha^2}\right).$$

- If $A = B$ and $k_A = k_B$, $T^{post} = D$ *i.e.* social optimal abatement

Green Tech and environmental regulation

- *Price Competition*: if $T^{ante} > D$, stronger in ex post: $(p_A^{post} - p_B^{post}) > (p_A^{ante} - p_B^{ante})$
- *Quality*: if $T^{ante} > D$, B invests less than A: $r_B^{ante} > r_B^{post}$; both underivest wrt the Social Optimum (under some conditions on the parameters!)
- *Adoption of the most efficient technology*: $T^{ante} < D$ is a sufficient condition to have $1 - \tilde{x}_B^{ante} < 1 - \tilde{x}_B^{post}$

- No direct competition between 2 technologies. Structure of the green tech game simplified.
- For technology A (symmetric results for technology B)

	Ex-ante	Ex-post
x_A	$\tilde{x}_A^{ante} = \frac{(O-A)T-k_A}{2\tau-\alpha^2}$	$\tilde{x}_A^{post} = \frac{(O-A)D-k_A}{2\tau-\alpha^2}$
r_A	$r_A^{ante} = \alpha x_A^{ante}$	$r_A^{post} = \alpha x_A^{post}$
p_A	$p_A^{ante} = \frac{\left(\tau-\alpha^2\right)k_A+\tau(O-A)T}{2\tau-\alpha^2}$	$p_A^{post} = k_A + \frac{\tau(O-A)D}{2\tau-\alpha^2}$

Table 1: Results in *case ii) for technology A*

Local Monopolies

- Optimal tax ex-ante

$$T^{ante} - D = \tau \frac{D\Big((O-A)^2+(O-B)^2\Big)-((O-A)k_A+(O-B)k_B)}{(\tau-\alpha^2)((O-A)^2+(O-B)^2)+(\alpha^2-2\tau)^2}$$

- Simple calculations show that the *ex ante* tax **exceeds** D **if and only if** both technologies are "socially desirable":

$$T^{ante} > D \Leftrightarrow$$
$$D(O-A) > k_A \text{ and } D(O-B) > k_B.$$

- *Ex post* taxation equals marginal damage.

Green Tech and environmental regulation: local monopolies

- *Price Competition*: if $T^{ante} > D + \frac{k_A - k_B}{A - B}$, stronger in *ex post*: $(p_A^{post} - p_B^{post}) > (p_A^{ante} - p_B^{ante})$
- *Quality*: if $T^{ante} > D$, B invests more than in the SO : $r_B^{SO} < r_B^{post}$
- *Adoption of the most efficient technology*: when $T^{ante} < D$, it is always the case that $1 - \tilde{x}_B^{ante} < 1 - \tilde{x}_B^{post}$

Ongoing work: environmental standards

- Further inefficiency: marginal abatement costs are not equalized
- In the previous literature, with two competing technologies and a fixed cost of adopting the most efficient one, uniform standards cause either full adoption, no adoption at all, partial adoption (Requate, EER, 2003)
- In our model, incentives for adoption cannot be simply calculated by comparing abatement and fixed adoption costs: here adoption costs endogenously depend on price and quality *i.e.* on competition
- The indifferent consumer will drive the comparisons

Conclusion

- Full characterization of equilibria allows us to map all previous literature's results
- The "quality" dimension compensates price competition in the green tech market
  - Policy Recommendation: T could **compensate distortions** due to market power in the tech sector:
  - If *ex-ante* taxation: tech firms set pricing strategies for given T^{ante}. Anticipating that firms will set prices higher than optimal, the regulator **should set a tax larger from marginal damage** to increase competition and adoption of the most efficient technology.
  - If *ex-post* taxation: tech firms anticipate that $T^{post} = SD'$ considering this in their maximization problem. This allows them to fix higher prices, which harms competition (solution is not SO) but this **may be better** than ex-ante regulation **in terms of quality.**

Thank you!