Environmental Regulating under Sequential Competition

Ana Espinola-Arredondo, Felix Munoz-Garcia, and
Pak-Sing Choi

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Motivation

- Sequential competition.
- Naturally arises in industries with intense innovation effort.
  - The innovator becomes the leader.
  - Historically well-documented in marketing, transportation, and supply chain industries.
- Recently shown in high tech:
  - Energy storage, batteries, electric grids, robotics, pharmaceutical and healthcare products, among others.
  - Rapidly expanding.
  - Polluting.
- Can we use the same environmental policy as if firms competed simultaneously?

Motivation

- **Research questions:**
  - How to regulate firms when they compete sequentially?
  - The leader produces more units than the follower in the absence of regulation (output advantage).
    - How is this output advantage affected by regulation?
  - To which extent the change in the leader's output advantage stems from:
    - Its first-mover advantage, or
    - Its cost advantage.
  - Role of *sequentiality* in:
    - output decisions (comparison against Cournot).
    - emission fees (comparison against firm-specific fees).

Literature

- Regulation with simultaneous competition:
  - Initiated by Buchanan (1969), symmetric costs, Levin (1985), asymmetric costs, Simpson (1995), asymmetric pollution intensities, Akhundjanov and Munoz-Garcia (2016), and price competition, Kurtyka and Mahenc (2011).
- Literature on "Stackelberg games" is just fee-then-Cournot-competition, one or multiple periods.
- Effect of environmental regulation on profits:
  - Porter (1991), Porter and van der Linde (1995), and Farzin (2013): examine how regulation can promote more innovation and product quality, increasing profits.
  - CSR/public image, Baron (2001, 2008) and Calveras and Ganuza (2016).
  - Alternative effect of regulation on profits: the attenuation of the leader's first-mover advantage.

Outline of the presentation

- Model
- Equilibrium behavior.
  - Without regulation (benchmark).
  - With regulation.
- Comparison with Cournot competition.
- Extensions:
  - Investment in abatement.
  - Several leaders and followers.
  - Firm-specific emission fees.
  - Product differentiation.

Model

- Consider inverse demand function $p(Q) = 1 - Q$, where $Q = q_1 + q_2$.
- Marginal costs:
    - c_1 (leader), c_2 (follower), where $c_2 \geq c_1$, and $c_i \in [0, 1]$.
- Using c_1 to normalize costs:
    - Follower:

$$c \equiv c_2 - c_1$$

    to denote the leader's cost efficiency.

Model - Environmental damages

- **Environmental damage**

$$ED = d(q_1 + q_2)^2,$$

where $d \geq 1/2$ represents pollution damage.

Model - Time structure

1. *First stage*:
   - The regulator sets an emission fee t.
2. *Second stage:*
   - The leader chooses output q_1.
3. *Third stage:*
   - The follower chooses output q_2.

- Output is sold at the end of the game.

Model - Time structure

- Social welfare is

$$W = CS + PS + T - ED,$$

  where:

  - $CS = \frac{Q^2}{2}$, $PS = \pi_1 + \pi_2$, and
  - $T = tQ$ represents total tax collection.

- $ED = dQ^2$ is the environmental damage from pollution.

Benchmark - No regulation

No environmental regulation

Benchmark - No regulation

- **Second stage:**
  - The follower takes q_1 as given and solves

$$\max_{q_2 \geq 0} \left(1 - q_1 - q_2\right) q_2 - cq_2$$

  - The follower's best response function is

$$q_2\left(q_1\right) = \begin{cases} \frac{1-c}{2} - \frac{1}{2} q_1 & \text{if } q_1 < 1 - c \\ 0 & \text{otherwise.} \end{cases}$$

Benchmark - No regulation

- **First stage:**
  - Anticipating $q_2(q_1)$, the leader solves

$$\max_{q_1 \geq 0} \quad [1 - q_2(q_1) - q_1]\, q_1$$

    which yields $q_1^{NR} = \frac{1+c}{2}$, where NR denotes for "no regulation."
  - Therefore, the follower's output in equilibrium is $q_2^{NR} = q_2\left(q_1^{NR}\right) = \frac{1-3c}{4}$, which is positive if $c < 1/3$.
  - $Q^{NR} = \frac{3-c}{4}$, which is decreasing in c.

Benchmark - No regulation

- The leader's output advantage (OA) is $\Delta q^{NR} \equiv q_1^{NR} - q_2^{NR} = \frac{1+5c}{4}$ or

$$\Delta q^{NR} = FMA^{NR} + CA^{NR} = \frac{1}{4} + \frac{5c}{4}$$

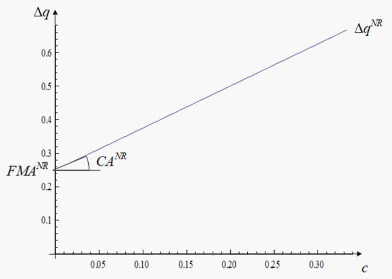

Fig. 1. Leader's OA

- How is each type of advantage affected by env. policy?

Introducing environmental regulation

Introducing environmental regulation

- **Third stage:**
  - *Lemma 1:* The follower's best response function is

$$q_2\left(q_1, t\right) = \frac{1-(c+t)}{2} - \frac{1}{2}q_1,$$

which is decreasing in c and t.

Introducing environmental regulation

- **Second stage:**
  - Lemma 2:
    - *The leader's output function is* $q_1(t) = \frac{1+c-t}{2}$.
    - *The follower's equilibrium output is* $q_2(t) = \frac{1-3c-t}{4}$.
    - *Both firms are active when* $t < \bar{t} \equiv 1 - 3c$.

Introducing environmental regulation

- **First stage:**
  - Anticipating $q_1(t)$ and $q_2(t)$, the regulator solves

$$\max_{t \geq 0} CS + PS + T - ED$$

- **Proposition 1.** *The emission fee is* $t^* = \frac{(3-c)(6d-1)}{9(1+2d)}$. *This fee induces:*

1. $q_1(t^*) = \frac{2[3+2c(1+3d)]}{9(1+2d)}$, *which is unambiguously positive, decreasing in* d, *but increasing in* c.
2. $q_2(t^*) = \frac{3-c(7+12d)}{9(1+2d)}$, *which is positive if and only if* $c < c_A \equiv \frac{3}{7+12d}$, *and decreasing in* d *and* c.

- **Emission fee:**
$$t^* = \frac{6d-1}{3(1+2d)} - \frac{6d-1}{9(1+2d)}c,$$
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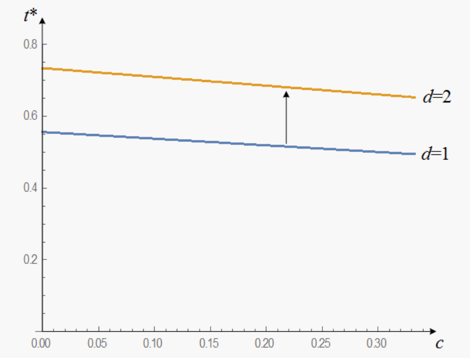

Fig. 2. Emission fee - Sequential

Introducing environmental regulation

- **Leader's output advantage (Corollary 1).**

$$\begin{aligned} \Delta q^R &= q_1(t^*) - q_2(t^*) \\ &= FMA^R + CA^R = \frac{1}{3(1+2d)} + \frac{11+24d}{9(1+2d)}c \end{aligned}$$

  - which is unambiguously positive and increasing in c but decreasing in d.
  - *FMA^R (CA^R) is decreasing (increasing) in d, and*
  - *$FMA^{NR} > FMA^R > 0$, and*
  - *$CA^R > CA^{NR} > 0$ for all admissible parameters.*

- **Comparing OA without and with regulation**
  - **Corollary 2:** *Emission fees produce an unambiguous reduction in the leader's output advantage, i.e.,*

$$\Delta = \Delta q^{NR} - \Delta q^{R} = \frac{(3-c)(6d-1)}{36(1+2d)} > 0$$

which increases in d but decreases in c.

Introducing environmental regulation

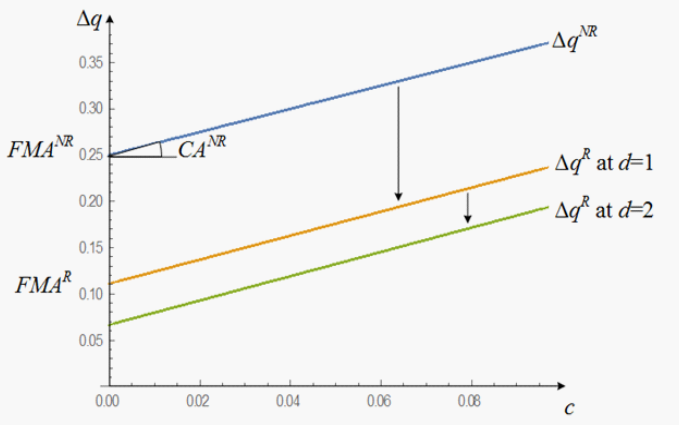

Fig. 3. Output advantage with regulation, Δq^R.

Introducing environmental regulation - Leader's Profits

- **Corollary 3.** *Equilibrium profits satisfy:*

1. $\pi_1^R > \pi_2^R$, *for all admissible parameters.*
2. *The leader's profit,* π_1^R, *is unambiguously increasing in* c *but decreasing in* d.
3. *The follower's profit,* π_2^R, *is unambiguously decreasing in* c *and* d.
4. *Every firm i's profit is higher without than with regulation,* $\pi_i^{NR} > \pi_i^R$.
5. *Regulation hurts the leader's profits more than the follower's,* $\Delta\pi_1 > \Delta\pi_2$.

Comparison with Cournot competition

Comparison with Cournot

- Output decisions

$$q_1^C(t) = \frac{1+c-t}{3} \quad \text{and} \quad q_2^C(t) = \frac{1-2c-t}{3},$$

  where C denotes Cournot competition. Note that $Q^C(0) < Q^{NR}$

- **No regulation.** Output levels simplify to $q_1^C(0) = \frac{1+c}{3}$ and $q_2^C(0) = \frac{1-2c}{3}$, entailing that OA becomes

$$\begin{aligned} \Delta q^{NR,C} &= q_1^C(0) - q_2^C(0) \\ &= \frac{1+c}{3} - \frac{1-2c}{3} = c. \end{aligned}$$

Comparison with Cournot - Regulation

- **Proposition 2.** *The emission fee is* $t^C = \frac{(2-c)(4d-1)}{4(1+2d)}$*, which is positive, decreasing in* c*, and increasing in* d*. This fee induces:*

1. $q_1^C\left(t^C\right) = \frac{2+c(1+4d)}{4(1+2d)}$*, which is decreasing in* d*, but increasing in* c*.*
2. $q_2^C(t^C) = \frac{2-c(3+4d)}{4(1+2d)}$*, which is positive if and only if* $c < c_B \equiv \frac{2}{3+4d}$*, and decreasing in* d *and* c*. Cutoff* c_B *is decreasing in* d*, satisfies* $c_B > c_A$*, and* $c_B \leq \frac{1}{3}$ *for all* $d \geq \frac{3}{4}$*.*

Comparison with Cournot

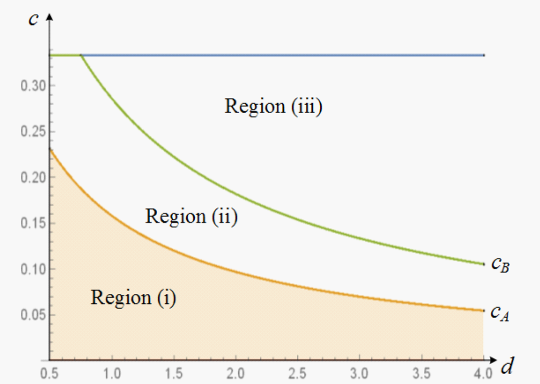

Fig. 4. Output profiles under Stackelberg and Cournot competition.

Comparison with Cournot

- **Output advantage.** Firm 1's output advantage with regulation, $\Delta q^{R,C} \equiv q_1^C(t^C) - q_2^C(t^C)$, becomes

$$\Delta q^{R,C} \equiv \frac{2 + c(1 + 4d)}{4(1 + 2d)} - \frac{2 - c(3 + 4d)}{4(1 + 2d)} = c, \qquad (6)$$

which coincides with that under no regulation, $\Delta q^{NR,C}$.

Comparison with Cournot

- **Fee comparisons: Cournot vs. Stackelberg:**
  - *The fee differential*

$$\Delta t \equiv t^* - t^C$$

is positive, increasing in c, but decreasing in d for all admissible parameters.

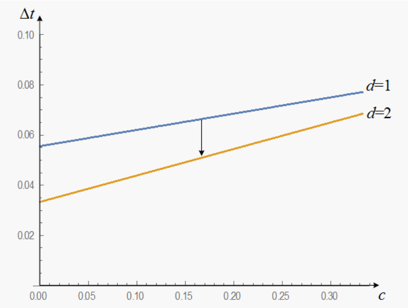

Fig. 5. Fee comparisons.

- **Fee errors:**
  - It is critical for regulators to assess whether firms compete simultaneously or sequentially when c is high and d is small.
  - In these industries, the "fee error" of assuming simultaneous competition and setting fee t^C in an industry competing sequentially is significant.
  - This error stems from setting a too lax emission fee, t^C instead of the more stringent t^*.
  - Firms produce a socially excessive production and, thus, pollution.
  - However, the fee error of assuming Cournot competition is small when c is low and d is high.

- **Welfare Loss**: $WL \equiv W(t^*) - W(t^C)$
- **Corollary 5.** *The welfare loss from setting Cournot fees in a Stackelberg industry,* $WL = \frac{[6+c(12d-5)]^2}{4608(1+2d)}$*, is unambiguously positive, increases in* c*, and decreases in* d*.*

- **Profit comparison: Cournot vs. Stackelberg**
  - Both firms are better off competing à la Cournot, including the leader.
  - This is in contrast to the profit ranking under no regulation, $\pi_1^{NR} > \pi_1^C(t^C)$.
    - A well-known misalignment of firm preferences with only firm 1 preferring Stackelberg competition.
  - Environmental policy helps "align" firm preferences, both being now in favor of Cournot competition.

Extensions

Extensions-I: Investments in abatement

- **Time structure**

1. First stage, the regulator sets emission fee t on every firm;
2. Second stage, every firm i invests in abatement, z_i,
    1. reduces emissions from q_i to $q_i - z_i$ at a cost of $\frac{\gamma}{2}(z_i)^2$.
3. Third stage, the leader chooses its output level, q_1; and,
4. Fourth stage, the follower responds with its own output, q_2.

Extensions-I: Investments in abatement

- In the second stage, however, the leader chooses its investment z_1 to solve

$$\max_{z_1 \geq 0} \pi_1 = \frac{(1+c-t)^2}{8} + tz_1 - \frac{\gamma}{2}(z_1)^2$$

which yields $z_1^*(t) = \frac{t}{\gamma}$. Similarly, the follower chooses z_2 to solve

$$\max_{z_2 \geq 0} \pi_2 = \frac{(1-3c-t)^2}{16} + tz_2 - \frac{\gamma}{2}(z_2)^2$$

obtaining that $z_2^*(t) = \frac{t}{\gamma}$.

Extensions-I: Investments in abatement

- First stage, the regulator anticipates z_i and q_i, solves

$$\max_{t \geq 0} \quad CS + PS + T - ED$$

where $T = t(Q - Z)$, $ED = d(Q - Z)^2$, and $Z = z_1 + z_2$ is aggregate investment in abatement. The emission fee is $t^{R\&D} = \theta t^*$, where

$$\theta = \frac{9\gamma(1+2d)[2d(8+3\gamma) - \gamma]}{(6d-1)[2d(8+3\gamma)^2 + 3\gamma(32+3\gamma)]}$$

and fee t^* was identified in Prop. 1. Weight θ is positive and satisfies $\theta < 1$.

Extensions-I: Investments in abatement

- θ is only a function of d and γ, thus being unaffected by c.
- Abatement produces a downward shift in emission fee, without affecting how rapidly it changes when the leader is more efficient (higher c).
- θ tends to 0 when $\gamma \to 0$, implying $t^{R\&D} = 0$.
- θ tends to 1 when $\gamma \to +\infty$, entailing that $t^{R\&D} = t^*$.

Extensions-I: Investments in abatement

- $$\Delta(\gamma) \equiv \Delta q^{NR}(\gamma) - \Delta q^{R}(\gamma) = \frac{(3-\gamma)\gamma[2d(8+3\gamma)-\gamma]}{8d(8+3\gamma)^2 + 12\gamma(32+3\gamma)}$$

  is positive, hence regulation unambiguously shrinks this firm's output advantage.
- $\Delta(\gamma)$ is unambiguously decreasing in c but increasing in d, as in the model without abatement; and increasing in γ.

Extensions-II: Leaders and followers

- **No regulation**. Every leader's OA is decreasing (increasing) in the number of leaders (followers).
- **Regulation.** The OA with regulation is unambiguously positive and increasing in d.
- Comparison:

$$\Delta(m,n) \equiv \Delta q^{NR}(m,n) - \Delta q^{R}(m,n).$$

- Overall, $\Delta(m,n)$ becomes smaller (larger) when more leaders (followers) compete, thus ameliorating (emphasizing) our previous results with a single leader and follower.

Extensions-III: Firm-specific fees

- **Proposition 4.** $t_1^* = \frac{8c}{1+2d}$ *and* $t_2^* = \frac{2d(3-c)-(5c+1)}{1+2d}$. *Fees rank as follows:*
  - *(i) if* $c > c_F$*, then* $t_1^* > t_2^* > t^*$*; (ii) if* $c_F \geq c > c_D$*, then* $t_2^* > t_1^* > t^*$*; and (iii) if* $c_D \geq c$*, then* $t_2^* > t^* > t_1^*$*, where both cutoffs increase in* d*, and satisfy* $c_F > c_D$*.*

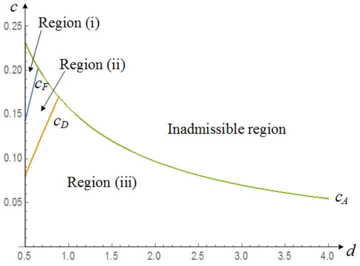

Fig. 6. Fee comparisons.

Extensions-III: Firm-specific fees

- **Welfare gains.** We evaluate the welfare gain $\Delta W \equiv W(t_1^*, t_2^*) - W(t^*)$
    - When firms are symmetric, using firm-specific fees does not provide any welfare gains, $\Delta W = 0$;
    - When firms are moderately asymmetric, $c < c_{\Delta W}$, firm-specific fees increase social welfare.
    - When firms are relatively asymmetric, $c \geq c_{\Delta W}$, firm-specific fees decrease welfare.

Extensions-IV: Product Differentiation

- **Allowing for product differentiation**
  - $p(q_i, q_j) = 1 - q_i - \beta q_j$, where $\beta \in [0, 1]$.
- We show that the leader's OA decreases when products are more differentiated (lower β).
  - This holds with and without regulation, but the latter falls more substantially.
  - In other words, the introduction of regulation produces a smaller decrease in the leader's OA.
    - Product differentiation ameliorates the reduction in OA that the leader suffers from regulation.
  - We should observe stronger opposition to env. policy when firms sell homogeneous than differentiated products.

Extensions-IV: Product Differentiation

- Edison Electric Institute, the main group of US electric utilities plants, recently lobbying against a Biden administration proposal to curb greenhouse gas emissions for existing gas power plants; see The Guardian (2023).
- EU steel association and German steel giant Thyssenkrupp opposing more stringent emission trading system rules; as reported by Politico (2022).

Discussion

- **No regulation**
  - OA is larger in Stackelberg ($FMA + CA$) than in Cournot (CA only).
  - OA decreases in the number of leaders, m, increases in the number of followers, n, and shrinks when goods become more differentiated (lower β).
- **Regulation**
  - $\Delta \equiv \Delta q^{NR} - \Delta q^{R} > 0$, for all parameters, meaning that OA shrinks due to regulation.
  - Δ shrinks in the leader's CA (higher c) but expands as pollution is more damaging.
  - The leader earns less profit than the follower with regulation.

Discussion

- **Regulation**
  - Leaders have "more to lose" from the enactment of environmental policies.
  - These finding are consistent with observed lobbying efforts against the Waxman-Markey Clean Energy bill (2009) by leading companies such as Boeing, Walmart Stores and Ford Motor Company, which spent $27.74 million, $9.34 million, and $9.1 million, respectively; Meng and Rode (2019).
- **Why not just apply Cournot regulation?**
  - Sequential competition requires more stringent t. Regulators incorrectly setting Cournot fees would induce a socially excessive pollution.
  - This inefficiency is the largest when d is low and c is high. Stackelberg fees are critical in this context.
  - This inefficiency is smaller when d is high and c is low. Policy design can ignore simultaneously or sequentially competition.

Further Research

- Asymmetric pollution intensities between the leader and the follower.
- Consider that one of the firms (leader or follower) is a publicly owned company.
- Allow for firms to compete in prices.
- Uncertainty about pollution damage.

Thank you!