Environmental Regulation, Incomplete information, and Game Theory
Day #1 - Common Pool Resources

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- Faysee (2005) for a nice literature review.
- Mason and Polasky (1994, 1997, 2002)

Benchmark - Complete information

- Consider a CPR with stock θ.
- First-period cost is $c(x_i) = \frac{x_i(x_i+x_j)}{\theta}$, where x_i denotes firm i's first-period appropriation.
- Second-period cost is $c(q_i, Q_{-i}) = \frac{q_i(q_i+q_j)}{\theta-(1-\beta)X}$,
  - where q_i represents second-period appropriation by firm i,
  - When $\beta = 1$, the stock fully regenerates and X doesn't affect second-period costs.
  - When $\beta = 0$, the stock does not regenerate and X fully affects second-period costs.
- Marginal costs are $\frac{2x_i+x_j}{\theta}$ and $\frac{2q_i+q_j}{\theta-(1-\beta)X}$, respectively; which are increasing in appropriation (total costs are convex) and decreasing in the initial stock (SCC holds).

Benchmark - Complete information

- What if there is only one firm?
- In the **second period**, the firm solves

$$\max_{q_i} \quad q_i - \frac{q_i^2}{\theta - (1-\beta)x_i}$$

yielding $q_i = \frac{\theta-(1-\beta)x_i}{2}$, and a second-period payoff of $\pi^{2nd}(x_i) = \frac{\theta-(1-\beta)x_i}{4}$.

- In the **first period**, taking $\pi^{2nd}(x_i)$ as given, the firm solves

$$\max_{x} \quad \underbrace{x_i - \frac{x_i^2}{\theta}}_{\text{First period}} + \delta \underbrace{\pi^{2nd}(x_i)}_{\text{Second period}}$$

yielding $x^* = \frac{\theta(3+\beta)}{8}$.

Benchmark - Complete information

- **Let us talk about inefficiencies...**
- In this case, the single firm fully internalizes the effect that its first-period appropriation has on the future stock.
- What if two firms operate in the second period? Two forms of inefficiencies:
  - During the first period, one of the firms ignores the effect that FPA has on its rival's profits; and
  - during the second period, each firm ignores the cost externality that its SPA has on its rivals. (See Espinola-Arredondo and Munoz-Garcia, 2011)
- What if two firms operate in the first and second period?
  - All the above inefficiencies (one per period) plus a new inefficiency during the first period; standard cost externality.

Benchmark - Complete information

- Two firms in each period. Solving the game by backward induction.
- **Second period:** Every firm i takes first-period appropriation as given, $X = x_i + x_j$, and solves

$$\max_{q_i} \quad q_i - \frac{q_i(q_i + Q_{-i})}{\theta - (1-\beta)X}$$

where the fish is sold at a competitive market, and price is normalized to one. Differentiating with respect to q_i and solving for q_i yields a best response function

$$q_i(q_j) = \frac{\theta - (1-\beta)X}{2} - \frac{1}{2}q_j$$

where the vertical intercept increases in the initial stock, θ, and in the regeneration rate, β, but decreases in previous appropriation, X.

Benchmark - Complete information

- **Second period:** In a symmetric equilibrium, $q_i = q_j = q$, entailing
$$q(X) = \frac{\theta - (1-\beta)X}{3},$$
yielding a second-period payoff of $\pi^{2nd}(X) = \frac{\theta-(1-\beta)X}{9}$.

Benchmark - Complete information

- **First period:** Every firm i anticipates $\pi^{2nd}(X)$ and solves

$$\max_{x} \underbrace{x_i - \frac{x_i(x_i + x_j)}{\theta}}_{\text{First period}} + \delta \underbrace{\pi^{2nd}(X)}_{\text{Second period}}$$

  Trick: express $\pi^{2nd}(X)$ as $\pi^{2nd}(x_i, x_j)$.

- Assuming for simplicity $\delta = 1$, and differentiating wrt x_i, yields the BRF

$$x_i(x_j) = \frac{\theta(8+\beta)}{18} - \frac{1}{2}x_j$$

  where the vertical intercept increases in the initial stock, θ, and in the regeneration rate, β. In a symmetric equilibrium, $x_i^* = x_j^* = x^*$, entailing

$$x^* = \frac{\theta(8+\beta)}{27}$$

Benchmark - Complete information

- **Social optimum.** In the second period, a social planner solves

$$\max_{q_i,q_j} \left[q_i - \frac{q_i(q_i+q_j)}{\theta-(1-\beta)X}\right] + \left[q_j - \frac{q_j(q_i+q_j)}{\theta-(1-\beta)X}\right]$$

  Differentiating with respect to q_i and q_j, and solving for them simultaneously yields

$$q_i^{SO}(X) = q_j^{SO}(X) = \frac{\theta-(1-\beta)X}{4}$$

  which is lower than in equilibrium, $q(X)$.

- Each firm's second-period payoff, evaluated at $q_i^{SO}(X)$ and $q_j^{SO}(X)$, is $\pi^{SO,2nd}(X) = \frac{\theta-(1-\beta)X}{8}$, which is also larger than that in equlibrium.

Benchmark - Complete information

- **Social optimum.** In the first period, a social planner solves

$$\max_{x_i, x_j} \left[x_i - \frac{x_i(x_i + x_j)}{\theta} + \pi^{SO,2nd}(X) \right] + \left[x_j - \frac{x_j(x_i + x_j)}{\theta} + \pi^{SO,2n$$

Differentiating with respect to x_i and x_j, and solving for them simultaneously yields

$$x_i^{SO} = x_j^{SO} = \frac{\theta(3+\beta)}{16}$$

which is lower than in equilibrium, $x^* = \frac{\theta(8+\beta)}{27}$, since $\frac{\theta(8+\beta)}{27} - \frac{\theta(3+\beta)}{16} = \frac{\theta(47-11\beta)}{432} > 0$ given that $\beta \leq 1$.

Alternative modeling strategies

- You may consider that firms face a downward sloping demand curve, $p(Q) = a - bQ$, rather than facing a perfectly competitive price p (which can be normalized to 1).
- Social welfare equal to aggregate profits, or

$$SW = \gamma CS + PS - Env,$$

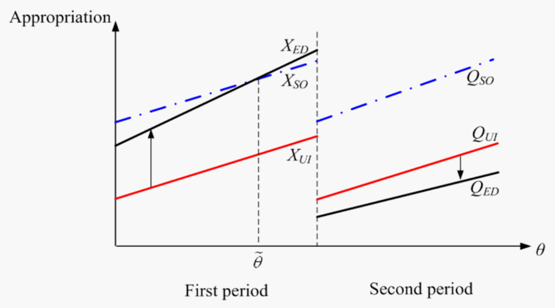
  - where $\gamma \in [0, 1]$ denotes the share of output sold domestically, and
  - $Env(Q) = dQ^2$ represents the environmental damage from appropriation (e.g., biodiversity loss) which is convex in appropriation.
  - When $\gamma = d = 0$ welfare collapses to PS, as in our above analysis (common in the literature).
- Symmetric cost functions across firms, or asymmetric functions?

Some contributions

- Our previous benchmark assumed no entry threats...
- Mason and Polasky (1994) examine how a single incumbent might strategically increase its exploitation of the CPR in order to prevent entry.
  - Hudson's Bay Company
  - They expanded that model to allow for multiple periods, in discrete time (1997 paper) or continuous time (2002).
- What about CPRs where more than a single incumbent operates?
  - Most CPRs have several incumbents.
  - Espinola-Arredondo and Munoz-Garcia (2013).
  - Setting is similar to Gilbert and Vives (1986) but allowing for intertemporal effects.

Entry deterrence in the commons

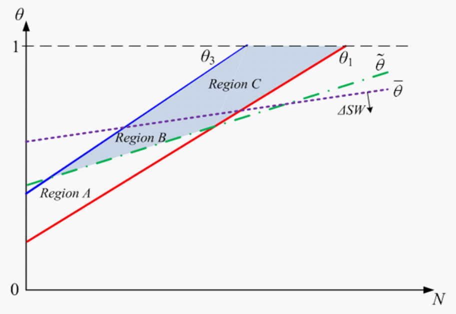
- UI denotes unthreatened incumbent.



Effects of entry deterrence on appropriation.

Entry deterrence in the commons

- Shaded region denotes overexploitation relative to SO.



Social welfare in the ED equilibrium

- (θ, N) $-$pairs below cutoff $\overline{\theta}$ indicate that SW increases relative to UI.

Ameliorating the "tragedy" of the commons

- Two main approaches in the literature:
- **Modify individual payoffs.** This essentially changes players incentives, even in a simple 2x2 matrix, but then we are not talking about a CPR game anymore!
  - Examples: Ostrom and Gardner (1994) and Ostrom (2009).
- **Insert the CPR game into an enlarged structure.** This approach doesn't alter the CPR game, but inserts it in a repeated-game context, or in an incomplete information setting.
  - Examples: Dutta and Sundaran (1993) Baland and Platteau (1996) for repeated games.
  - Examples: Suleiman and Rapoport (1988), Suleiman et al. (1996), and Apesteguia (2006). Mostly experimental, and all players are uninformed.

What if we allow for signaling in the commons?

- Espinola-Arredondo and Munoz-Garcia, JEEM 2011.
- Time structure:
  - Nature determines the realization of the stock, either θ_H or θ_L, with prob. p and $1-p$, respectively.
  - The incumbent observes the stock's realization, and chooses FPA, x.
  - The entrant observes x, but not θ, updates its beliefs $\mu(\theta_H|x)$ and $\mu(\theta_L|x)$, and chooses to enter or not enter the CPR.
  - If entry does not occur, the inc. remains alone; if entry occurs, both agents compete for the CPR.

What if we allow for signaling in the commons?

- Signaling model is similar to Milgrom and Roberts (1982).
  - With an important difference: FPA affects second-period profits.
- This also differs from Polasky and Bin (2001) who, for simplicity, assume that incumbent and entrant operate in different CPRs.
- Methodology can be applied to other research questions, where first-period actions not only convey/conceal information to other players, but affect both players' payoffs in subsequent stages.

What if we allow for signaling in the commons?

- **New inefficiencies emerge relative to complete info:**
  - In the separating PBE:
  - The low-stock incumbent underexploits the resource to convey its type. (No additional inefficiencies if the stock is high type.)
  - Under a low-stock inc, incomplete info. leads to more inefficiencies than in CI.
  - *Example*: Silver hake in the North Atlantic, blackfin tuna in the Caribbean, among others.

What if we allow for signaling in the commons?

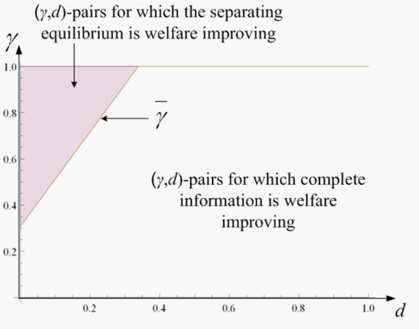
- **New inefficiencies emerge relative to complete info:**
  - In the pooling PBE:
  - The high-stock incumbent underexploits the resource to conceal its type, but exploits it at the SO level in the second period.
  - Under a high-stock inc, incomplete info. may lead to welfare gains relative to CI.
  - *Example*: Coastal fishing communities in Loreto.

More on signaling in the commons

- Espinola-Arredondo and Munoz-Garcia, Econ Letters 2013.
- Consider now regulators with $SW = \gamma CS + PS - Env$;
- In the above signaling game, has the regulator incentives to acquire info and disseminating it to potential entrants? Or does he prefer to keep potential entrants "in the dark"?
  - That is, is SW higher under complete info or incomplete info; and is our answer affected by the stock's actual level?

More on signaling in the commons

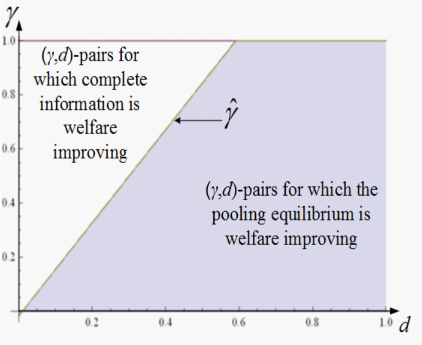
- In a separating PBE, overall exploitation is larger than under CI, yielding three welfare effects: (1) a larger CS; (2) a lower PS because ED effort relative to CI; and (3) larger Env damage.
- Effect (1) offsets (2) and (3) if $\gamma > \overline{\gamma}$...



Welfare omparisons under θ_L

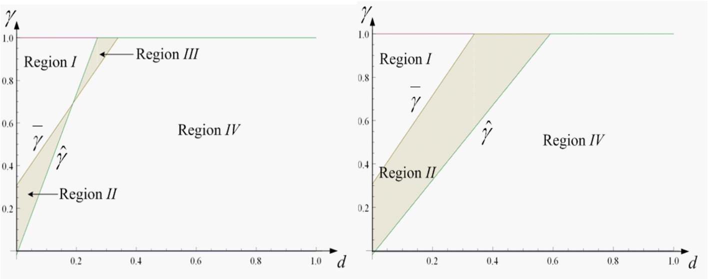
More on signaling in the commons

- In a pooling PBE, overall exploitation is smaller than under CI. Welfare effects are then: (1) a lower CS; (2) a larger PS since ED is achieved while it didn't in CI; and (3) smaller Env damage.
- Effects (2) and (3) offset (1) if $\gamma < \widehat{\gamma}$...



More on signaling in the commons

- But the regulator is uninformed!



$\beta = 0.2.$ $\beta = 0.6.$

- In Region II (III) SW decreases (increases) regardless of the stock.

Extensions

- In the JEEM paper:
  - What if a sequence of entrants seek to enter? Chain-store approach
  - What if the CPR has multiple incumbents?
    - Then pooling PBE is more difficult to sustain, or perhaps unsustainable; as in Harrington (1986) and Schultz (1999) for standard IO models of limit pricing.
    - Separating PBE then coincides with equilibrium behavior under CI.

Extensions

- In the SBE paper:
  - What if we consider a stock, rather than a flow, externality?
  - What if entrants do not have information about the CPR's profitability, and use the incumbents' appropriation to infer this info?

Thank you!!!