Common pool resources: quality vs quantity

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08-12-2021

Background and motivation

- Following housing, transport, travel and food, clothing industry is responsible for environmental degradation (European Environmental Agency, 2014)
- As per World Bank, coloring and dyeing processes account for 17-20 percent modern water contamination worldwide
- Textile companies draw water from a nearby resource for dyeing and finishing processes. After using this water, textile companies are required to treat the toxic water before letting it back into the river or lake.

Background and motivation

- The quality of water bodies gets degraded because textile industries let out harmful effluents without proper treatment [Kasthuri et al., 2007]
- Textile industries in Bangladesh fall under the category of "Red Industries" and according to 'ECA, 1995'and 'ECR 1997' textile industries have treat water as per the standard of national discharge quality [Huq, 2003].
- Textile water pollution in southern India led to severe impact on the health of the people living in vicinity,ground water and reduced productivity of farms [Arumugam and Elangovan, 2009]

Contribution to existing literature

- Quantity of commons [Ostrom, 1990].
- 'Tragedy of commons' due to exploitation and over consumption [HARDIN, 1968]
- lack of literature on qualitative degradation of common pool resources [Sarker et al., 2008].
- Attempt to construct a model to analyse the qualitative degradation of a common pool resource when the firm is using the resource as an input in production.
- Analyze how profits of a firm gets impacted due to qualitative degradation of the common pool resource.

Model

- The model is adopted from common pool resources [Espinola-Arredondo and Munoz-Garcia, 2021]
- Two stage sequential game under dynamic setting
- Incumbent operates in first and stage and potential entrant decides whether to enter or not in second stage

Incumbent's profit in stage one

$$\max_{q_i \geq 0} \pi_i^{1st} = q_i - \frac{q_i(q_i + Q_{-i})}{S} \tag{1}$$

Every firm i in stage two solves

$$\max_{q_i \geq 0} \pi_i^{2nd} = q_i - \frac{q_i(q_i + q_j)}{S - (1 - r)x} \tag{2}$$

Model

- Consider a two stage sequential game of complete information.
- Two symmetric textile firms/ duopoly i and j, selling homogeneous goods.
- Firms operate under perfect competition.Firms take prices as given.
- For simplicity normalize price to 1

Model: with abatement

Stage one

- Firms face extraction cost for drawing a certain percentage of water for dyeing clothes.
- Firms face abatement cost where each firm i treats water before letting it back into CPR.

Stage two

- Firms face extraction cost for drawing a certain percentage of water for dyeing clothes.
- CPR regenerates in second stage.
- Operations end at the end of second stage

Since this is a model under complete information lets assume that the firms abate in first stage such that there is always some water to extract in next stage.

Model: with abatement

Stage one variables

- w_{i1} is the percentage of water that firm i extracts from CPR in stage one.
- w_{j1} is the percentage of water that firm j extracts from CPR in stage one (competitor).
- $0 < \gamma \leq 1$ is the inherent quality of the water in CPR.
  $\gamma \to 1 \implies$ quality of CPR is better
  $\gamma \to 0 \implies$ quality of CPR is poor
- C_a is the abatement cost that firm i faces in stage 1

Model: with abatement

Profit of firm i in stage one is

$$\pi_{i1} = w_{i1} - \frac{w_{i1}(w_{i1} + w_{j1})}{\gamma} - \frac{C_a w_{i1}}{\gamma} \tag{3}$$

- $\frac{w_{i1}(w_{i1} + w_{j1})}{\gamma}$ is the extraction cost that firm i faces in stage 1
- $\frac{C_a W_{i1}}{\gamma}$ is the abatement cost that firm *i* faces in stage 1

Model: with abatement

Stage two variables

- $0 \leq r$ is the regeneration rate, e.g : rainfall
  When $r = 1 \implies$ CPR fully regenerates. In other words it means that the CPR is the same as it was in stage one .
  If $r < 1$ is situation in which drought occurs
  If $r > 1$ means there was abundant rainfall which improves the quality of CPR in stage 2.

Model: with abatement

Profit of firm i in stage two is

$$\pi_{i2} = w_{i2} - \frac{w_{i2}(w_{i2} + w_{j2})}{r[\gamma - \alpha w_{i1} - \beta w_{j1}]} \tag{4}$$

- Firms don't abate in stage two because operations end.
- $\alpha \in [0, 1]$ and $\beta \in [0, 1]$: quality degradation parameters.
- $\frac{\partial \pi_{i2}}{\partial \alpha} < 0$ and $\frac{\partial \pi_{i2}}{\partial \beta} < 0$
  $\alpha = \beta \to 0 \implies$ lower extraction costs and vice versa

Model: without abatement

Profit of firm i in stage one is

$$\pi_{i1} = w_{i1} - \frac{w_{i1}(w_{i1} + w_{j1})}{\gamma} \tag{5}$$

Profit of firm i in stage one is

$$\pi_{i2} = w_{i2} - \frac{w_{i2}(w_{i2} + w_{j2})}{r[\gamma - w_{i1} - w_{j1}]} \tag{6}$$

- Note that firms would face lowest extraction cost when $\gamma r \leq 1$. Hence the range of regeneration rate is now redefined as $0 \leq r \leq \frac{1}{\gamma}$.
- $w_{i1} + w_{j1} < 1$ meaning firms do not extract all water from the CPR.

Results:without abatement

Taking first order condition and rearranging variables, yields best response function as:

$$w_{i2} = \frac{r[\gamma - w_{i1} - w_{j1}]}{2} - \frac{w_{j2}}{2} \tag{7}$$

Lemma

1.1 The second period profits as a function of first period percentage of water extractions for each firm i are given as:

$$\pi_{i2} = \frac{r[\gamma - w_{i1} - w_{j1}]}{9} \tag{8}$$

The first period profits are given as: $\pi_{i1} + \delta\pi_{i2}$, where $\delta \in [0, 1]$ is the discount rate.Thus we have:

$$\pi_{i1} = w_{i1} - \frac{w_{i1}(w_{i1} + w_{j1})}{\gamma} + \delta\frac{r[\gamma - w_{i1} - w_{j1}]}{9}$$

Results:without abatement

$$\pi_{i1} = w_{i1} - \frac{w_{i1}(w_{i1} + w_{j1})}{\gamma} + \delta \frac{r[\gamma - w_{i1} - w_{j1}]}{9}$$

The first order condition of the above equation and obtain best response function, we get:

$$w_{i1} = \frac{\gamma}{2}[1 - \frac{\delta r}{9}] - \frac{w_{j1}}{2}$$

$$\frac{\partial w_{i1}}{\partial \delta} = -\frac{\gamma r}{18} < 0$$

- Intuitively if the firm values second stage profits more,the it will extract less water in first stage and consequently earn lower profits

Results:without abatement

Proposition

1. The profits that each firm i earns in second stage of the game are:

$$\pi_{i2} = \frac{r\gamma}{243}[9 + 2\delta r]$$

Lemma

1.2 Second stage profits are

1. *increasing with regeneration/ rainfall* $\frac{\partial \pi_{i2}}{\partial r} = \frac{2r\gamma\delta}{243} + \frac{1}{243}[\gamma(9 + 2r\delta)] > 0$
2. *increasing in the quality of CPR* $\frac{\partial \pi_{i2}}{\partial \gamma} = \frac{1}{243}[r(9 + 2r\delta)] > 0$
3. *increasing in discounting rate rate* $\frac{\partial \pi_{i2}}{\partial \delta} = \frac{2r^2\gamma}{243} > 0$

Results: without abatement

Proposition

2. The profits that each firm i earns in first stage of the game are:

$$\pi_{i1} = \frac{1}{729}\gamma(9 + 2r\delta)^2$$

Lemma

2.1 First stage profits are

1. *increasing with regeneration/ rainfall* $\frac{\partial \pi_{i1}}{\partial r} = \frac{4}{729}\gamma\delta(9 + 2r\delta) > 0$;
2. *increasing quality of CPR* $\frac{\partial \pi_{i1}}{\partial \gamma} = \frac{1}{729}(9 + 2r\delta)^2 > 0$

Results : with abatement

Taking first order condition and rearranging variables, yields best response function as:

$$w_{i2} = \frac{r[\gamma - \alpha w_{i1} - \beta w_{j1}]}{2} - \frac{w_{j2}}{2}$$

Lemma

3.1 The second period profits as a function of first period percentage of water extractions for each firm i are given as:

$$\pi_{i2} = \frac{r[\gamma - \alpha w_{i1} - \beta w_{j1}]}{9} \tag{9}$$

The first period profits are given as: $\pi_{i1} + \delta\pi_{i2}$, where $\delta \in [0, 1]$ is the discount factor

$$\pi_{i1} = w_{i1} - \frac{w_{i1}(w_{i1} + w_{j1})}{\gamma} - \frac{C_a w_{i1}}{\gamma} + \delta \frac{r[\gamma - \alpha w_{i1} - \beta w_{j1}]}{9}$$

Results : with abatement

Proposition

3 The profits that each firm i earns in second stage of the game are:

$$\pi_{i2} = \frac{1}{243}[r(9C_a(\alpha+\beta) - 9(\alpha+\beta-3)\gamma + 2r(\alpha^2 - \alpha\beta + \beta^2)\gamma\delta]$$

Lemma

3.2 Second stage profits are

1. *increasing with regeneration/ rainfall* $\frac{\partial \pi_{i2}}{\partial r} > 0$
2. *increasing quality of CPR* $\frac{\partial \pi_{i2}}{\partial \gamma} > 0$
3. *increasing in discounting rate* $\frac{\partial \pi_{i2}}{\partial \delta} > 0$

Results with abatement

Lemma

3.2 (contd.) Second stage profits are

1. *decreasing in* α *and* $\beta \implies \frac{\partial \pi_{i2}}{\partial \alpha}, \frac{\partial \pi_{i2}}{\partial \beta} < 0$, *which holds only if* $C_a < \gamma(1 - \frac{2}{9} r(2\alpha - \beta)\gamma\delta)$ *and* $C_a < \gamma(1 - \frac{2}{9} r(2\beta - \alpha)\gamma\delta)$ *respectively*

Finally the first stage profits are

Proposition

4 The profits that each firm i earns in first stage of the game are:

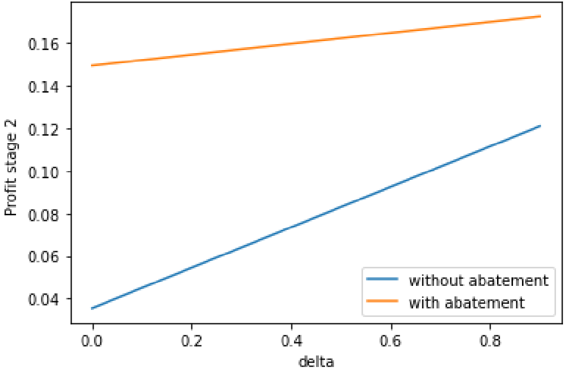
$$\pi_{i1} = \frac{81(c-\gamma)^2 + 9r\gamma((4\alpha+\beta)(c-\gamma) + 9\gamma)\delta + r^2(4\alpha^2 - 7\alpha\beta + 7\beta^2)\gamma^2\delta^2}{729\gamma}$$

Graphical comparison: with v/s without abatement

Parameter values:

$\gamma = 0.8, \delta = 0.95, r = 1.011, \alpha = \beta = 0.3, C_a = 2.4$

Second stage Profits, with and without abatement



Graphical comparison: with v/s without abatement

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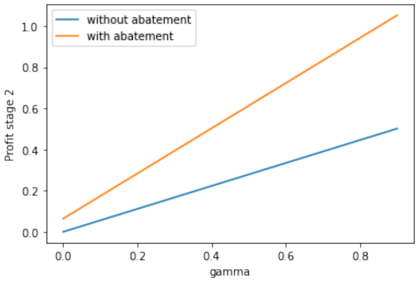

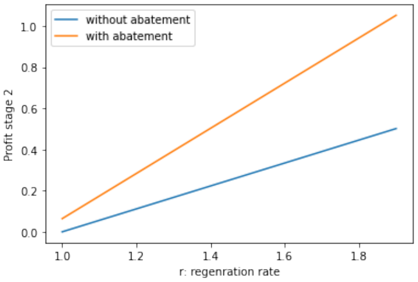

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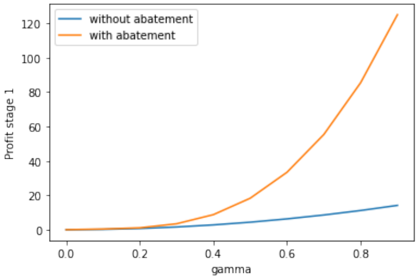
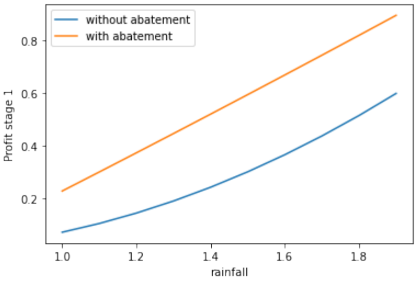
First stage Profits, with and without abatement



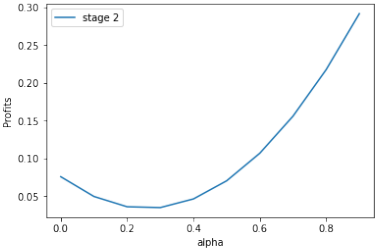


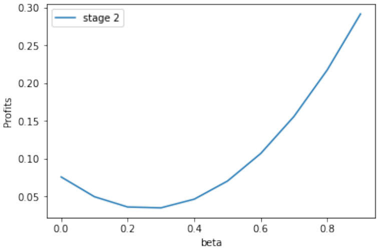
Graphical comparison: with v/s without abatement

Parameter values: $\gamma = 0.8, \delta = 0.95, r = 1, \alpha = \beta = 0.3, C_a = 2.4$

Second stage Profits, with and without abatement

Case 1 Impact on quality degradation parameters when CPR fully regenerates





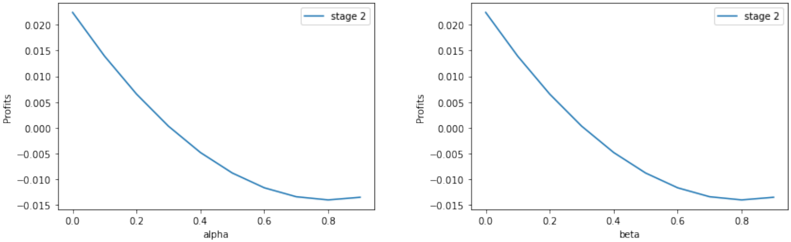
Graphical comparison: with v/s without abatement

Parameter values:

$\gamma = 0.8, \delta = 0.95, r = 1.011, \alpha = \beta = 0.3, C_a = 2.4$

Second stage Profits, with and without abatement

Case 2 Impact on quality degradation parameters when drought occurs



Socially optimum appropriation:aggregate profits

Taking w_i1 and w_j1 as give, the maximization problem in stage two of the game is given as follows.

$$\max_{w_{2i}, w_{2j} \geq 0} = \pi_{i2} + \pi_{j2}$$

$$\implies w_{i2} - \frac{w_{i2}(w_{i2} + w_{j2})}{r[\gamma - \alpha w_{i1} - \beta w_{j1}]} + w_{j2} - \frac{w_{j2}(w_{i2} + w_{j2})}{r[\gamma - \alpha w_{i1} - \beta w_{j1}]}$$

In the first period, the social planner maximizes the aggregate profits of first stage and discounted welfare from second stage.

$$\max_{w_{i1}, w_{j1}} \pi_{i1} + \pi_{j1} + \delta[\pi_{i2} + \pi_{j2}]$$

Socially optimum appropriation:aggregate profits

Proposition

5. The second period appropriation is $w_{i2}^{SO} = \dfrac{r(\gamma - \alpha w_{i1} - \beta_{w_j 1})}{4}$ *and first period appropriation is* $w_{i1}^{SO} = \dfrac{1}{27}(9C_a - \gamma(9 + r(-2\alpha + \beta)\delta))$.

Comparing the first and second stage appropriations to model with abatement leads to dynamic inefficiency.
Second stage

$$w_{i2} - w_{i2}^{SO} = \frac{7r(\gamma - \alpha w_{i1} - \beta_{w_j 1})}{12} > 0$$

First stage

$$w_{i1} - w_{i1}^{SO} = \frac{7\gamma}{12} - \frac{7C_a}{12} - \frac{r\gamma\delta(5\alpha - \beta)}{432} > 0$$

Which holds for all values of values of the parameter

Further research

- Consider a model under incomplete information where firms decide whether or not to abate by introducing probabilities
- Consider a two stage incumbent- entrant game where agents use qualitative degradation of CPR as a signal to deter entry

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