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Dynamic games applied to common resources: modeling and experimentation - preliminary analysis

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Without regulation, Common Pool Resources (CPR) are subject to overexploitation (Hardin, 1968)

Ex: forest, earth, groundwater, fish stocks.

To correctly anticipate the effect of regulation, we need to understand how agents take decisions.
Objectives

- Clarify some ambiguities between discrete and continuous time, and the time horizon chosen for lab experiments

- What type of behavior will the experimental subjects exhibit: feedback, myopic, open-loop or social optimum?

- Continuous time can be approached by discrete time $\Rightarrow$ confront theory with experimentation
Literature

- Theoretical article: Rubio & Casino (2003) ⇒ continuous time, infinite horizon

- Lab experiment: Janssen & al. (2010) ⇒ spatial aspect

- Theoretical with lab experiment:
  - Herr & al. (1997) ⇒ discrete time, finite horizon
  - Oprea & al. (2014) ⇒ compares continuous and discrete time
  - Tasneem & al. (2017) ⇒ continuous time, infinite horizon
Model

- Infinite horizon framework

- Study the exploitation behavior of a renewable groundwater table by 2 identical and symmetrical farmers ⇒ optimal control and game

- the continuous time problem:

\[
\max_{w_i(t)} \int_0^\infty e^{-rt} \left[ \begin{array}{c}
aw_i(t) - \frac{b}{2}w_i(t)^2 - c_t(H(t))w_i(t) \\
\text{Gross profit}
\end{array} \right] dt
\]

\[
\begin{cases}
H(t) = R - \alpha w_i(t) & : \text{the optimal control} \\
H(t) = R - \alpha \sum w_i(t) & : \text{the game} \\
w_i(t) \geq 0 \\
H(t) \geq 0
\end{cases}
\]

\[H(0) = H_0, \text{ and } H_0 \text{ given}\]
The theoretical model

Infinite horizon modeling

Model

- Calibration:
  \[ a = 2.5; b = 1.8; \alpha = 1; R = 0.56; c_0 = 2; c_1 = 0.1; r = 0.005; H_0 = 15 \]

- The unitary cost is such that:
  \[
  c_t(H(t)) = \begin{cases} 
  (c_0 - c_1 H(t)) & \text{if } 0 \leq H(t) < 20 \\
  0 & \text{if } H(t) \geq 20
  \end{cases} \Rightarrow \begin{cases} 
  (2 - 0.1 H(t)) & \text{if } 0 \leq H(t) < 20 \\
  0 & \text{if } H(t) \geq 20
  \end{cases}
  \]
The theoretical model

Infinite horizon modeling

illustrations: extraction behaviors

Figure – The game: feedback, myopic, open-loop and social optimum
Theoretical model
Infinite horizon modeling

Model

- the **discrete time** problem:

\[
\max_{w_{i,n}} \sum_{n=0}^{\infty} \left( 1 - r\tau \right)^n \left[ aw_{i,n} - \frac{b}{2} w_{i,n}^2 - c_n(H_n)w_{i,n} \right] \beta^n \tau
\]

\[
\begin{cases}
H_{n+1} = H_n + \tau \left( R - \alpha w_{i,n} \right): \text{the optimal control} \\
H_{n+1} = H_n + \tau \left( R - \alpha \sum w_{i,n} \right): \text{the game} \\
w_i(t) \geq 0 \\
H(t) \geq 0
\end{cases}
\]

\[
H(0) = H_0, \text{ and } H_0 \text{ given}
\]

- Continuous & discrete time: availability of all formulas for the optimal control and the game
Feedback: groundwater table $H(t)$ convergence for $\tau = 1$
Experimental design

2 treatments

- Continuous time
  - 2 parts in each treatment
    - Optimal control
      - 2 five minutes training
      - The experiment
    - Game
      - 2 five minutes training
      - The experiment

- Discrete time
Experimental design

- No contextualization
- common knowledge experimentation with full information

Subject were informed that...

« You initially have 15 resource units. At any time, you can take a quantity between 0 and 2.8 resource units, with a precision of two decimal places. You are free to choose the quantity you want to take, namely 0, 0.01, 0.02... 2.79, 2.8 »
## Preliminary results - continuous time

<table>
<thead>
<tr>
<th>Game</th>
<th>Feedback</th>
<th>Myopic</th>
<th>Optimal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
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<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Optimal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myopic</td>
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<td>2</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Optimal</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
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<td>3</td>
<td>11</td>
<td>40</td>
</tr>
</tbody>
</table>

**Figure** – Behavior in the optimal control and the game
Discussion and conclusion

We found that:

- Continuous time model \(\equiv\) discrete time model when \(\tau \to 0\)
- But \(\tau = 1\) also works \(\Rightarrow\) easy to understand in experimentation

The question is...

Which model best represents the reality?

- Subjects who were myopic in optimal control mostly played feedback in the game
- Econometric analysis not complete \(\Rightarrow\) correct time-series treatments
Further works

First of all:

- Discrete time lab experiment

- Experimentation: continuous time vs discrete time model

Then:

- Test the game without the optimal control

- Modify the given information $\Rightarrow$ dynamics of the resource vs dynamics of costs
Thank you for your attention!!