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

Murielle Djiguemde, Dimitri Dubois, Mabel Tidball and Alexandre Sauquet

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Motivation

- 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 ⇒ confront theory with experimentation
Outline

1. Introduction
   - Motivation
   - Literature

2. The theoretical model
   - Infinite horizon modeling
     - The optimal control
     - The game

3. Theory and experimentation
   - Econometric analysis in continuous time
     - Preliminary results - continuous time

4. Further works

5. Discussion and conclusion

6. Further works
Introduction

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:

\[
\max_{w_i(t)} \int_0^\infty e^{-rt} \left[ a w_i(t) - \frac{b}{2} w_i(t)^2 - \left( c_t(H(t)) w_i(t) \right) \right] dt
\]

\[
\begin{align*}
\dot{H}(t) &= R - \alpha w_i(t) : \text{the optimal control} \\
\dot{H}(t) &= R - \alpha \sum w_i(t) : \text{the game} \\
w_i(t) &\geq 0 \\
H(t) &\geq 0 \\
H(0) &= H_0, \text{ and } H_0 \text{ given}
\end{align*}
\]
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:

  \[
  c_t(H(t)) = \begin{cases} 
  (c_0 - c_1 H(t)) & \text{if } 0 \leq H(t) < 20 \\
  0 & \text{if } H(t) \geq 20
  \end{cases}
  \begin{cases} 
  (2 - 0.1H(t)) & \text{if } 0 \leq H(t) < 20 \\
  0 & \text{if } H(t) \geq 20
  \end{cases}
  \]
illustrations: extraction behaviors

**Figure** – *The game: feedback, myopic, open-loop and social optimum*
Model

- the **discrete time** problem:

\[
\max_{w_i \in \mathbb{R}} \sum_{n=0}^{\infty} (1 - r \tau)^n \left( \frac{b}{2} w_i^2 - c_n(H_n)w_i \right) \beta^n \]

\[
\begin{cases}
H_{n+1} = H_n + \tau (R - \alpha w_i n) : \text{the optimal control} \\
H_{n+1} = H_n + \tau (R - \alpha \sum w_i n) : \text{the game}
\end{cases}
\]

\[
w_i(t) \geq 0, \quad H(t) \geq 0
\]

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

- Continuous & discrete time: availability of all formulas for the optimal control and the game
The theoretical model

Infinite horizon modeling

Illustrations: continuous and discrete time comparison

**Figure** – Feedback: groundwater table $H(t)$ convergence for $\tau = 1$
Experimental design

2 treatments

- Continuous time
- Discrete time

2 parts in each treatment

- Optimal control
  - 2 five minutes training
  - The experiment

- Game
  - 2 five minutes training
  - The experiment
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

### Game

<table>
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<tr>
<th>Type</th>
<th>Feedback</th>
<th>Myopic</th>
<th>Optimal</th>
<th>Total</th>
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<td>Other</td>
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<td>0</td>
<td>1</td>
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<tr>
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<td></td>
<td>26</td>
<td>3</td>
<td>11</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!!