Bargaining around the Prey-Refuge

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Aix✻Marseille université Socialement engagée

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Motivation (1)

- Habitat support marine life
  - Source of food; shelter against predators; serves as nursery ground..
- A definition of habitat
  - "the place where **multiple** species live together under similar environmental conditions" IFREMER report (2010)

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Motivation (2)

▷ **This paper** $\Longrightarrow$ introduce the habitat as a protective function against natural predation in an economic framework

- The case of a prey-refuge as protective function
  - Prey are protected from **natural** predation but not from **human** predation ($\neq$ MPAs)

- The economic interest
  1. Change the intensity of species inter-dependencies $\Longrightarrow$ **direct** (opposite) impact on fish stocks and **indirect** (opposite) impact on fishing and welfare
  2. As a way to restore economic efficiency in exploiting species $\Longrightarrow$ **Artificial refuges**

$\Longrightarrow$ Goal : Convince you that there exists some economic gains over the construction of AR's

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Research Questions

Research Questions

1. How does the presence of a prey-refuge impact fisheries **welfare** in exploiting predator-prey ecosystems?
2. What are the economic **trade-offs** that underlie cooperative behavior in the implementation of a prey-refuge?

Methodology

▷ The two-stage game

1. Fisheries cooperatively bargain over prey refuge construction and distribution of surplus.
2. Fisheries behave non-cooperatively when exploiting a predator-prey system with the established refuge.

▷ Solving backwards

1. Derive the non-cooperative Feedback Nash equilibrium for a predator-prey system with a prey-refuge
2. Derive the cooperative Nash Bargaining solution to analyze refuge implementation and surplus sharing conditions

$\Longrightarrow$ Cooperative behavior among competitors $\rightarrow$ **"Coopetition"**

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Related Literature & Contributions

Literature

▷ Mathematics and Theoretical Bio. that introduce prey-refuge into P-P systems

- The refuge protect a constant share of preys from the predator

$\Longrightarrow$ **BUT**, mainly for system stability purpose without economic considerations

▷ Fishery economics accounting for habitat

- Endogenized bio. parameters; Habitat dynamics; Marine protected Areas (MPAs)

$\Longrightarrow$ **BUT**, mainly for conservation purpose without ecosystem based consideration

Contributions

1. Combine both strand of literature by rationalizing the utilization of ARs
2. New approach to manage fisheries

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Outline

Introduction

The model

Non-cooperative harvesting with prey-refuge

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Appendix

Population Dynamics

▷ Modified Lotka-Volterra P-P equations

$$\begin{aligned}\dot{x}(t) &= A_x\sqrt{x(t)} - \delta_x x(t) - b_x\sqrt{(1-r)x(t)y(t)} - h_x(t), \quad x(0) > 0 \\ \dot{y}(t) &= A_y\sqrt{y(t)} - \delta_y y(t) + b_y\sqrt{(1-r)x(t)y(t)} - h_y(t), \quad y(0) > 0\end{aligned} \tag{1}$$

▷ Biological parameters $\Longrightarrow A_s, \delta_s, b_s$ for $s = x, y$

▷ Prey Refuge $\Longrightarrow rx(t)$

▷ Harvesting $\Longrightarrow h_s(t)$ for $s = x, y$

Economic Activities

Ecosystem Games $\Longrightarrow$ **Fish Wars**

1. Two Fishers (or countries) specializing in harvesting distinct fish types $s = x, y$
2. Payoffs function arising from harvesting activities

$$\forall s = x, y \qquad U^s\left((h_s(t))_{t\geq 0}\right) = \int_0^{\infty} 2\sqrt{h_s(t)}\exp^{-\rho t}\, dt \tag{2}$$

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Outline

Introduction

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Cooperative Bargaining problem

A Stylized Example

Conclusion

Appendix

The Differential Game

- ▷ Understand how the refuge **impacts** fisheries payoffs

$$\max_{h_x(t)\geq 0} \int_0^{\infty} 2\sqrt{h_x(t)}exp^{-\rho t}dt \quad \Big| \quad \max_{h_x(t)\geq 0} \int_0^{\infty} 2\sqrt{h_y(t)}exp^{-\rho t}dt$$

$$\dot{x}(t) = A_x\sqrt{x(t)} - \delta_x x(t) - b_x\sqrt{(1-r)x(t)y(t)} - h_x(t)$$
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$$x(0), y(0) > 0$$

The Differential Game

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Existence of a linear species-specific Feedback-Nash equilibrium

Proposition 1

Within the context of linear harvesting strategies, a unique Feedback Nash Equilibrium (FBNE) emerges, characterized by $\{h_x(t), h_y(t)\} = \{\omega_x^{NE} x(t), \omega_y^{NE} y(t)\}$ *where* $\{\omega_x^{NE}, \omega_y^{NE}\}$ *solve the following system of equations:*

$$\left(2\rho - \omega_x^{NE} + \delta_x\right)\left(2\rho + \delta_y + \omega_y^{NE}\right) + b_x b_y (1 - r) = 0 \tag{3}$$

$$\left(2\rho - \omega_y^{NE} + \delta_y\right)\left(2\rho + \delta_x + \omega_x^{NE}\right) + b_x b_y (1 - r) = 0 \tag{4}$$

Comparative Statics

▷ Applying the Implicit Function Theorem (IFT), the effects of the prey-refuge on the fishing pressure are:

	ω_x^{NE}	ω_y^{NE}
Proportion of protected prey (r)	$-$	$-$

Table: Prey-refuge and catch rates

Remark 1

This does not mean that harvesting decreases!

Payoffs as a Function of the Refuge Size

▷ Non-cooperative equilibrium payoffs of fishers:

$$U^s(r) = 2\sqrt{\omega_s^{NE}(r)} \int_0^\infty e^{-\rho t} \sqrt{s(t, r)} dt, \quad s \in \{x, y\} \tag{5}$$

⟹ Fisheries understand the manner in which the refuge affects their welfare!

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The model

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Cooperative Bargaining problem

A Stylized Example

Conclusion

Appendix

The Problem

- Are there **efficient** and **equitable** agreements on the size of the refuge?
  1. Are there any gains associated with cooperating on building a specific refuge size?
  2. If yes, how should this surplus be shared among fisheries?

- The Cooperative (Nash) Bargaining Setting
  - Axiomatic approach ($\neq$ strategic approach)
  - The bargaining process is abstracted
  - Transferable Utility (TU) $\rightarrow$ fishers can compare payoffs and make transfers
  - The prey-refuge construction can be costly

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Welfare Gains from Cooperation

▷ Does a **cooperative surplus** ($\mathcal{CS}$) exist? Examining the **total transferable wealth**, $\mathcal{W}(r)$:

$$\mathcal{W}(r) = \int_0^\infty \left[2\sqrt{\omega_x^{NE}(r)x(t,r)} + 2\sqrt{\omega_y^{NE}(r)y(t,r)} - \Phi(r)\right] e^{-\rho t} dt, \tag{6}$$

$\Longrightarrow$ Payoff of the prey fisher; Payoff of the predator fisher; Cost function

▷ Existence of $\mathcal{CS} > 0$

$$\exists\, \mathcal{CS} > 0 \iff \mathcal{W}(r^*) > U^x(0) + U^y(0) \tag{7}$$

$\Longrightarrow$ Disagreement payoffs

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⟹ Disagreement payoffs

The Bargaining Problem

▷ The set of **possible payoffs**

$$S = \{(U^x(r), U^y(r)) \in \mathbb{R}^2_+ : U^x(r) + U^y(r) \leq \mathcal{W}(r^*)\} \tag{8}$$

$\Longrightarrow$ TU implies a linear Pareto Frontier

▷ The **disagreement payoffs**

$$d = (U^x(0), U^y(0)) \in \mathbb{R}^2_+ \tag{9}$$

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The Nash Bargaining Solution

▷ Under five reasonable axioms → Nash (1950)

- The solution to (S, d) is to maximize the **Nash product**

$$(U^x_{\mathcal{NB}}, U^y_{\mathcal{NB}}) = \underset{U^x(r), U^y(r) \in S}{\arg\max} \left[(U^x(r) - U^x(0)) \cdot (U^y(r) - U^y(0)) \right] \tag{10}$$

- The unique solution

$$U^x_{\mathcal{NB}} = \frac{1}{2} (\mathcal{W}(r^*) - U^y(0) + U^x(0)) \quad ; \quad U^y_{\mathcal{NB}} = \frac{1}{2} (\mathcal{W}(r^*) - U^x(0) + U^y(0)) \tag{11}$$

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Outline

Introduction

The model

Non-cooperative harvesting with prey-refuge

Cooperative Bargaining problem

A Stylized Example

Conclusion

Appendix

The Total Transferable Wealth: The case of no prey-refuge cost

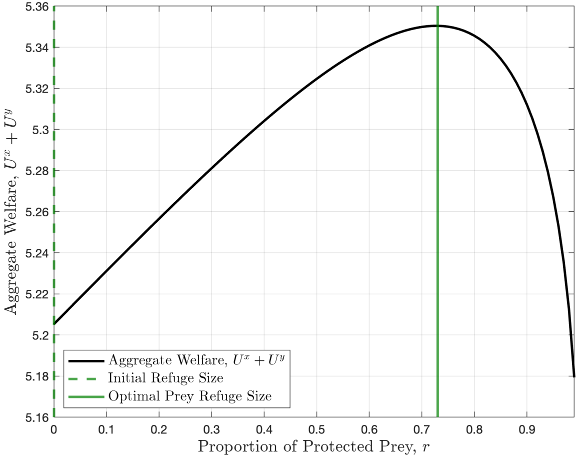

Figure: Welfare as a Function of the Refuge Size

Mechanism $\Longrightarrow MB = MC$

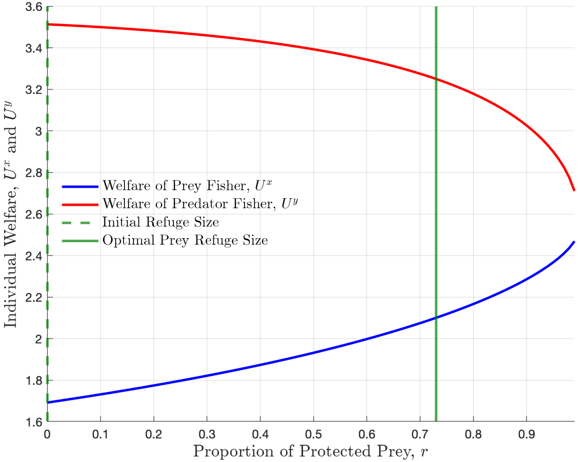

Figure: Welfare per Fisher as a Function of the Refuge Size

The Sharing Rule

$\Longrightarrow$ The cooperative solution $\rightarrow$ equally share the triangle

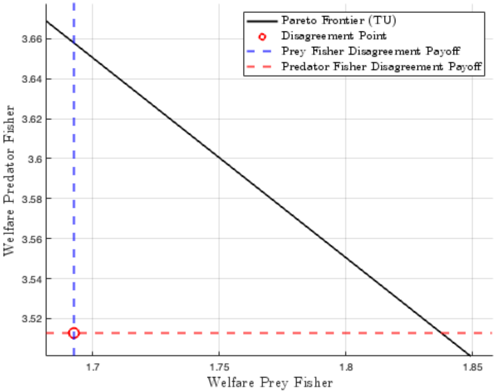

Figure: The Cooperative Solution (TU)

Outline

Introduction

The model

Non-cooperative harvesting with prey-refuge

Cooperative Bargaining problem

A Stylized Example

Conclusion

Appendix

To Wrap Up

- Two main questions addressed in the paper

1. How does the refuge impact fishery welfare?
   - **Reduce** fishing pressure but has **opposite** effects on welfare.
2. What are the economic trade-offs in prey-refuge implementation?
   - $MB = MC$ without prey refuge cost.
   - Agreement on a **smaller** refuge when the construction is **costly**.

$\Longrightarrow$ **Artificial refuges can be welfare-relevant for fisheries**

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Limits

$\Longrightarrow$ Fishing on the refuge

$\Longrightarrow$ Proportional prey-refuge $\Longrightarrow$ Stock dependant cost

$\Longrightarrow$ Time-consistency

$\Longrightarrow$ Limits as $r \to 1$?

Outline

Introduction

The model

Non-cooperative harvesting with prey-refuge

Cooperative Bargaining problem

A Stylized Example

Conclusion

Appendix

Artificial refuges (1)

Figure: Artificial refuge (1)

Artificial refuges (2)

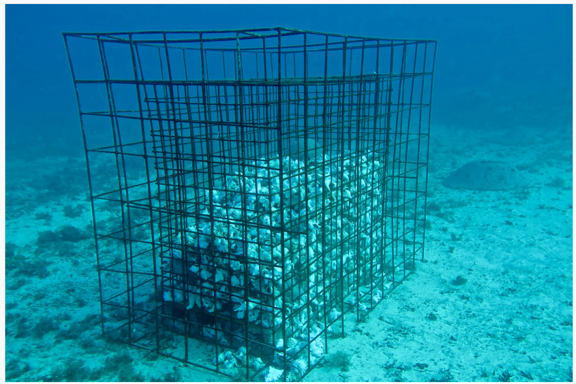

Figure: Artificial refuge (2)

Existing Prey-Refuge

$\Longrightarrow$ If a prey-refuge of size $\mathbf{r_0}$ already exists:

- The disagreement point may change, leading to either lower or higher bargaining power for fishers.
- This change could either reduce or increase the cooperative surplus $\rightarrow$ see figure.
- The cooperative solution may contribute to improve or destroy the existing refuge.

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Prey-Refuge Cost

$\Longrightarrow$ The (de-)construction of the prey-refuge can become costly with $\Phi(r) = \xi(r - r_0)^2$

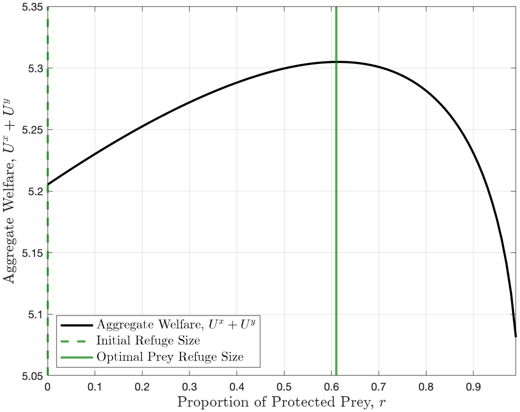

Figure: Welfare with Costly Refuge: $\xi = 0.1$

Optimal Management and Prey-Refuge

$\Longrightarrow$ What would a sole owner managing harvesting and prey-refuge do?

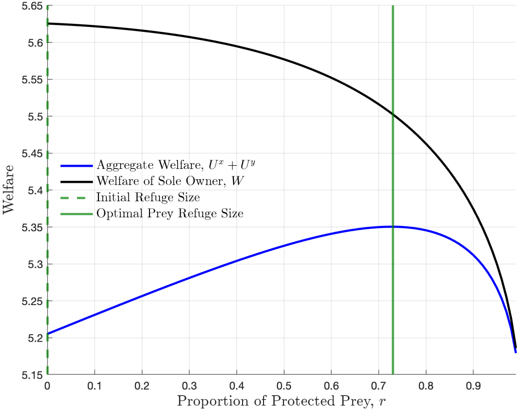

Figure: Optimal vs. Decentralized Welfare

Non-Transferable Utility

$\Longrightarrow$ Does Pareto-improving allocations without transfers exist within this example?

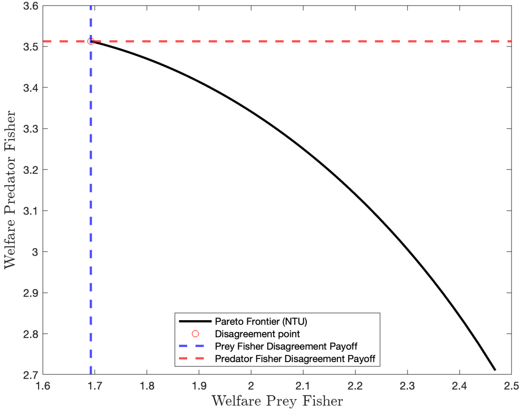

Figure: The Cooperative Solution (NTU)

Alternative Solution Concepts

$\Longrightarrow$ How do the results depend on the choice of the solution concept (Nash Bargaining)?

- Examples include Kalai-Smorodinsky, Shapley value, Utilitarian, Egalitarian, etc.

▷ In Transferable Utility (TU) $\rightarrow$ all the same!

▷ In Non-Transferable Utility (NTU) $\rightarrow$ all are different:

- $\mathcal{KS}$ $\rightarrow$ emphasizes on aspiration $\rightarrow$ the disagreement point is more important
- Shapley $\rightarrow$ provides a proportional payoff based on the marginal contribution
- etc.

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