Marine Reserves as a Cooperation Mechanism in Transboundary Fisheries

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Camp Resources

The problem of internationally shared fish stocks

- Global empirical evidence that internationally shared fish stocks are more exploited than non-shared stocks (McWhinnie 2009).
- Spatial connectivity creates an externality in resource extraction.
- Non-cooperative resource extraction leads to overexploitation and profit loss; optimal management requires coordination between countries (Munro 1979, Levhari and Mirman 1980).

Marine reserves as a spatial management tool

- Marine reserves create networks of spatial closures that protect marine resources from fishing pressure.
- Broad literature on consequences of introducing marine reserves on fishery profits and stock abundance (e.g. Smith and Wilen 2003).
- Economic and ecological benefits of marine reserves depend on underlying stock biology and current state of fisheries management (e.g. Hilborn et al. 2004, Sanchirico et al. 2006).

Research Question

Can the establishment of a no-take marine reserve in a transboundary fishery produce first-best economic outcomes?

Main Results

- Marine reserve implementation can yield first-best economic outcomes equivalent to cooperative resource extraction.
- Marine reserve implementation can improve economic outcomes resulting from non-cooperative extraction for a range of stock dependent marginal harvest costs.

Model Overview

- Two countries A and B share a fish stock.
- The proportion of the fishery area that lies in country A is denoted $\alpha \in (0, 1)$.
- Countries are price-takers and have identical harvest costs.
- Countries harvest a fixed fraction of adult stock density, $H_j \in [0,1]$, where j $\in \{A, B\}$.
- Compare equilibrium outcomes under several management scenarios.

Main Assumptions

Assumption 1. Adult movement

Adults are sedentary.

Assumption 2. Larval dispersal

Larvae are distributed uniformly throughout the fishery so that the density of juveniles attempting to settle at any location is constant.

Assumption 3. Density dependence

The density of larvae successfully recruited to the adult population at any location depends only on the density of juveniles attempting to settle in that location.

Assumption 4. Marginal harvest costs

Marginal harvest costs are stock independent.

Biological Model

Beverton-Holt stock-recruitment relationship:

$$f(d) = \frac{\gamma_1 d}{1 + \gamma_2 d} \tag{1}$$

Stock density in country j evolves according to:

$$n_{j,t+1} = (1 - H_j)[f(m(\alpha n_{A,t-k} + (1-\alpha) n_{B,t-k})) + a n_{j,t}] \tag{2}$$

In equilibrium, stock in each country satisfies:

$$\begin{aligned} n_A &= (1 - H_A)[f(m(\alpha n_A + (1-\alpha) n_B)) + a n_A] && (3) \\ n_B &= (1 - H_B)[f(m(\alpha n_A + (1-\alpha) n_B)) + a n_B] && (4) \end{aligned}$$

Economic Model

Country-level equilibrium yields:

$$\begin{aligned} Y_A &= \alpha H_A[f(m(\alpha n_A + (1-\alpha)n_B)) + a n_A] \quad (5) \\ Y_B &= (1-\alpha)H_B[f(m(\alpha n_A + (1-\alpha)n_B)) + a n_B] \quad (6) \end{aligned}$$

Country-level profits:

$$\pi_j = PY_j - \int_{n_j^{post}}^{n_j^{pre}} \frac{\theta}{n} dn \quad (7)$$

Management Scenarios

- **Cooperative extraction:** each country chooses a harvest rate to maximize the joint profits of both countries.
- **Non-cooperative extraction:** each country chooses a harvest rate to maximize own profits taking the harvest rate of the other country as given.
- **Marine reserve implementation:** each country agrees to commit a proportion, r, of its fishery area to marine reserves and then chooses a harvest rate in its remaining fishery area to maximize own profits taking the harvest rate of the other country as given.

Proposition 1.

For any transboundary fishery such that Assumptions 1-4 are satisfied, total profits under cooperative extraction are greater than total profits under non-cooperative extraction.

Adding a Marine Reserve

Equilibrium biological constraints:

$$\begin{aligned} n_A &= (1-H_A)[f(m(\alpha(1-r)n_A + (1-\alpha)(1-r)n_B + rn_R)) + an_A] && (8) \\ n_B &= (1-H_B)[f(m(\alpha(1-r)n_A + (1-\alpha)(1-r)n_B + rn_R)) + an_B] && (9) \\ n_R &= f(m(\alpha(1-r)n_A + (1-\alpha)(1-r)n_B + rn_R)) + an_R && (10) \end{aligned}$$

Equilibrium country-level yields:

$$\begin{aligned} Y_A &= \alpha(1-r)H_A[f(m(\alpha(1-r)n_A + (1-\alpha)(1-r)n_B + rn_R)) + an_A] && (11) \\ Y_B &= (1-\alpha)(1-r)H_B[f(m(\alpha(1-r)n_A + (1-\alpha)(1-r)n_B + rn_R)) + an_B] && (12) \end{aligned}$$

Proposition 2.

For any transboundary fishery such that Assumptions 1 - 4 are satisfied, there exists an optimal reserve fraction, r*, such that total profits under optimal reserve implementation equal total profits from cooperative extraction.

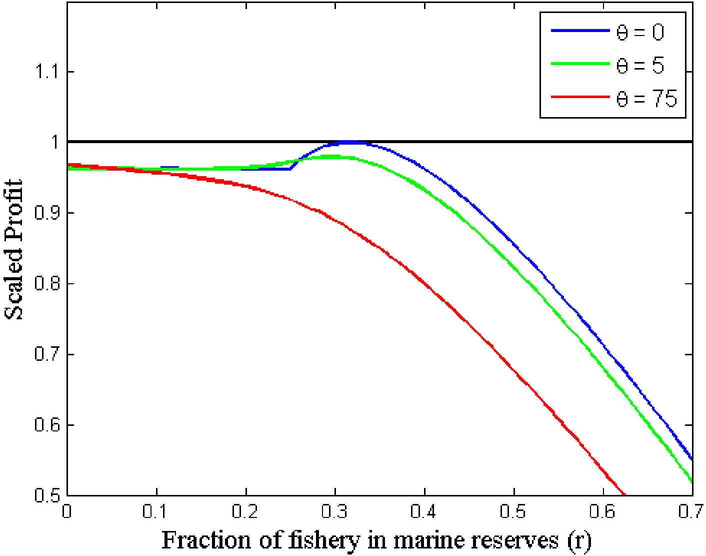
Proposition 3.

For a range of $\theta > 0$, total profits under optimal reserve implementation, r*, are greater than total profits from non-cooperative extraction.

Example

Parameter	**Description**	**Value**
α	Proportion of fishery in country A	0.5
a	Natural adult survival probability	0.8
m	Per capita larval production	2
γ_1	Beverton-Holt parameter	1
γ_2	Beverton-Holt parameter	0.00045
p	Price($/fish)	1
θ	Stock effect coefficient ($/area)	0, 5, 75

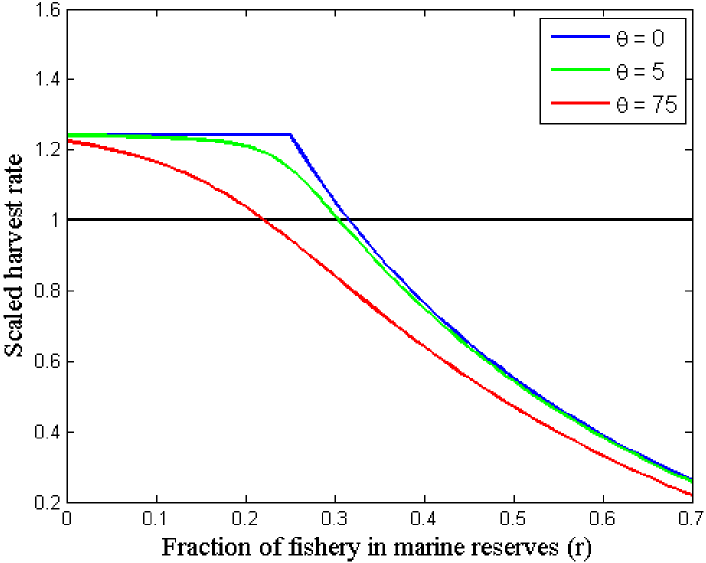
Scaled Profit



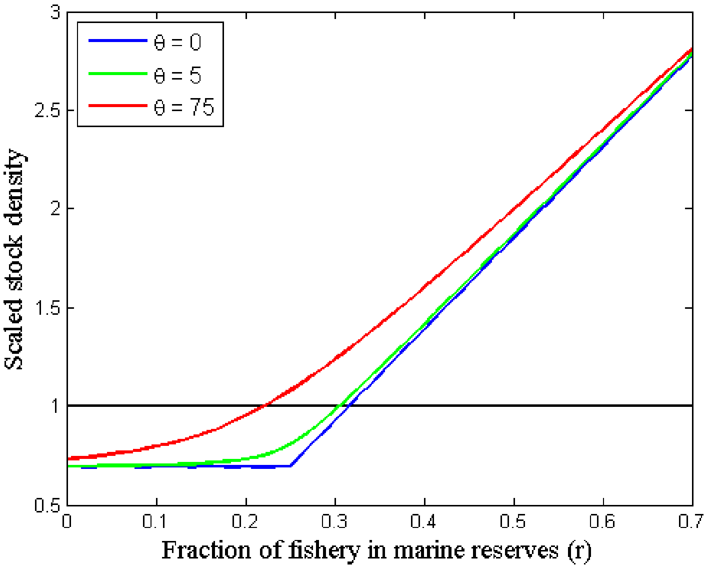
Conclusions

- Possible to get first-best economic outcomes in a transboundary fishery using marine reserves as a cooperative management tool.
- Capacity of marine reserves to improve economic outcomes will depend on stock dynamics, fishing technology, and current state of management.
- Putting theory into practice: Peru-Chile achoveta fishery.

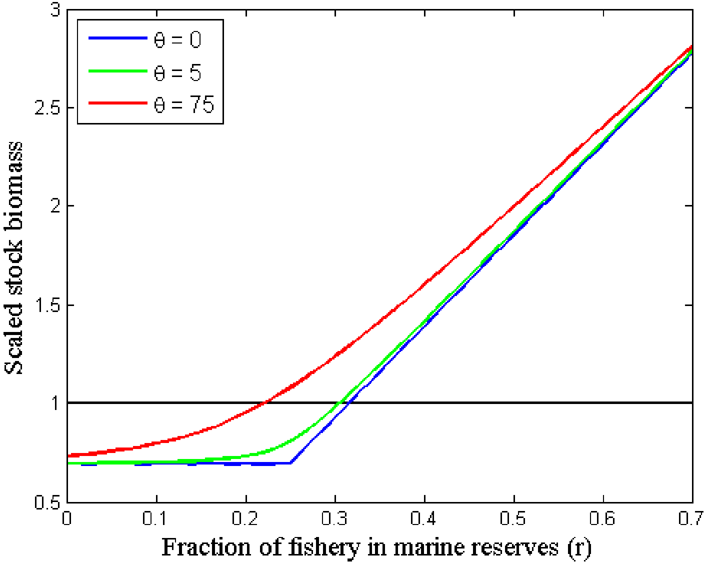
Scaled Harvest Rate



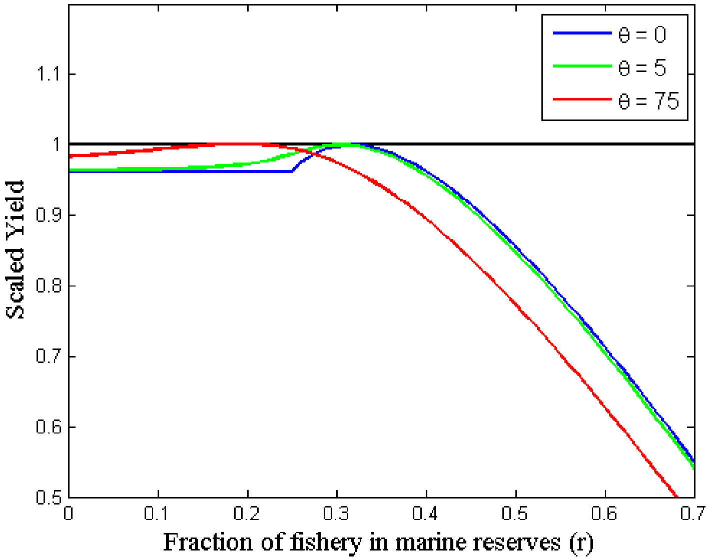
Scaled Stock Density



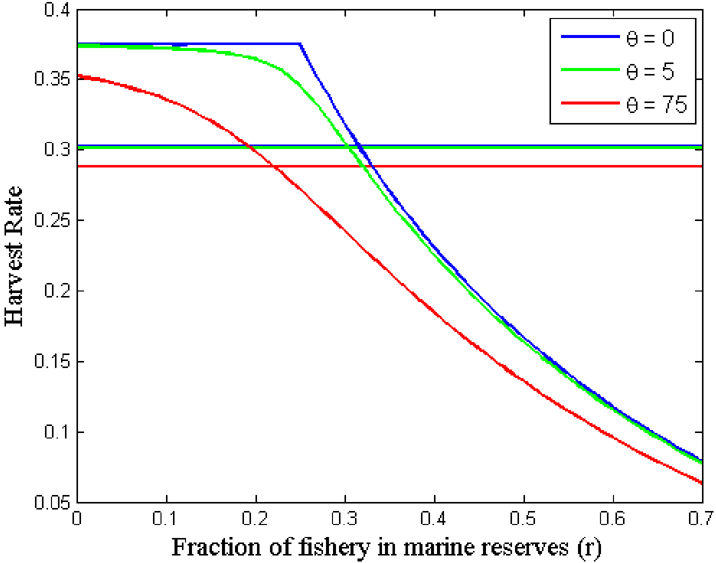
Scaled Stock Biomass



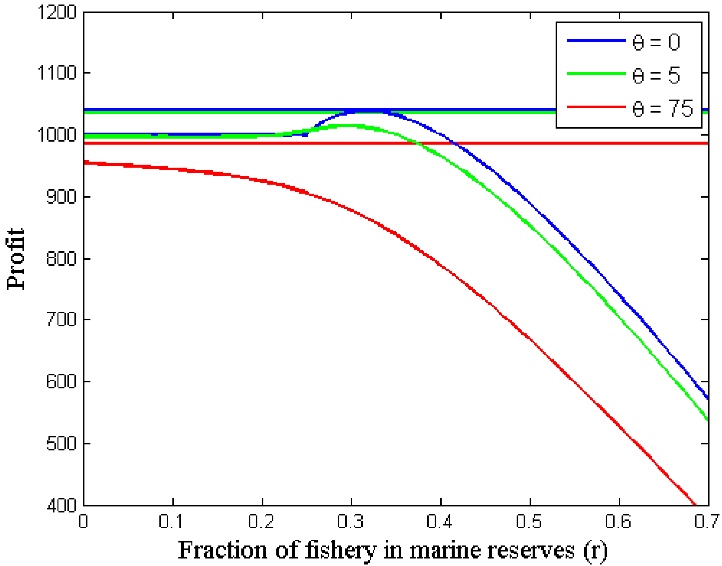
Scaled Yield



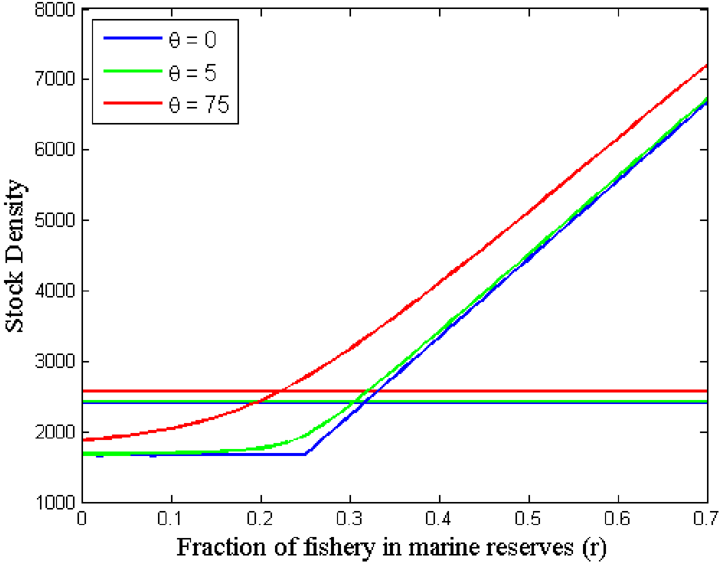
Harvest Rate



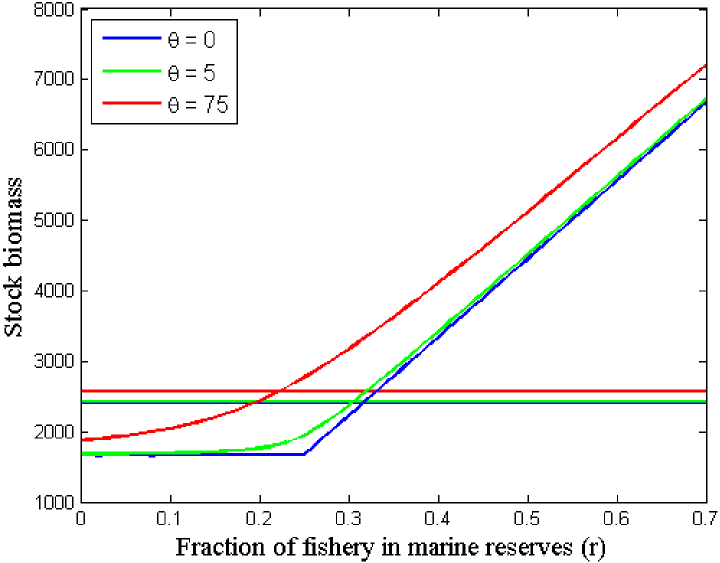
Profit


θ = 0
θ = 5
θ = 75
Profit
1200
1100
1000
900
800
700
600
500
400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Fraction of fishery in marine reserves (r)

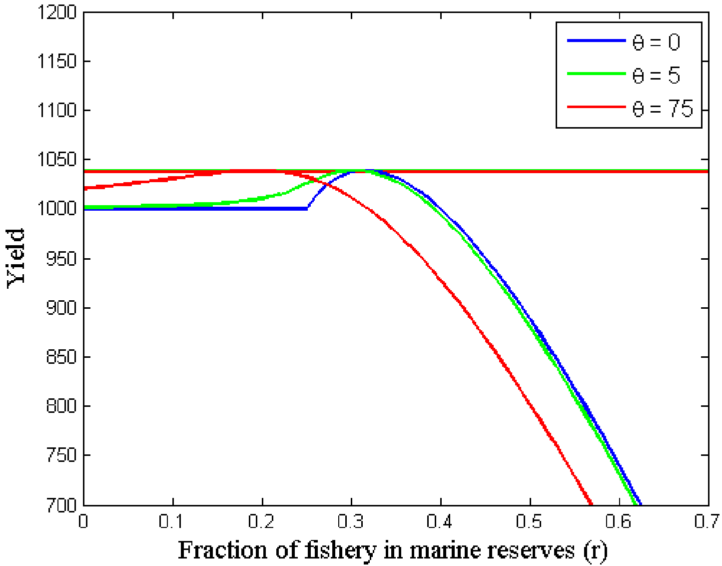
Stock Density



Stock Biomass



Yield


1200
1150
1100
1050
1000
950
900
850
800
750
700
Yield
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Fraction of fishery in marine reserves (r)
θ = 0
θ = 5
θ = 75