Optimal Fisheries Contracts with Asymmetric Information and Interdependent Species

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Introduction

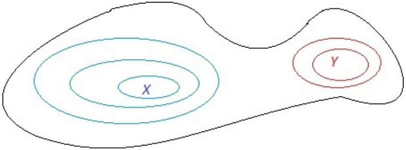

Figure: Commercial species x and non-commercial species y

- Two fish stocks competing for a resource (x is commercial and y is non-commercial)
- Presently, only commercial species regulation is common
- Two-species regulation can increase stock of x and lead to larger revenues if y is lowered
- Two-species regulation may fail due to asymmetry of information

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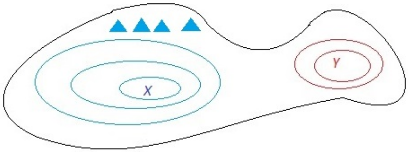

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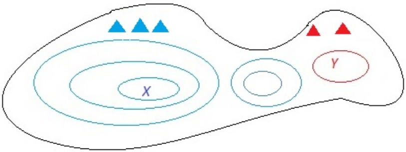

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Ecological-Economic Model. Gordon-Schaefer model.

- Two species: commercial x and non-commercial y
- Fish stock S_j, $j = x, y$, logistic growth function

$$\dot{S}_j = G_j(S_j) = r_j S_j (1 - \frac{S_j}{K_j}),$$

where r_j is intrinsic growth rate, K_j is carrying capacity, S_j is stock j;

- $n = 2$ fishing fleets (two players) can harvest x and y simultaneously
- Purely selective fishing:
  e_{ij} is (**strategy**) harvesting effort of species j of fisherman i.
  Total effort of harvesting x is E_x, and total effort of harvesting y is E_y.
- Individual harvest j of fisherman i is

$$h_{ij}(e_j, S_j) = q_j S_j e_{ij},$$

where q_j is catchability coefficient.

Ecological-Economic Model

- Assumption: K_y is given, but K_x depends on S_y

$$K_x = K_{x0}\left(2 - \frac{S_y}{K_y}\right)^{\alpha},$$

K_{x0} is carrying capacity x if y is not harvested,
S_y is stock y,
K_y is species y carrying capacity,
α indicates **how competing stocks are**, so that $0 \leq \alpha \leq \overline{\alpha}$.

- Steady state of fish stocks are

$$\tilde{S}_y = K_y(1 - \frac{q_y}{r_y}(e_{1y} + e_{2y})),$$

$$\tilde{S}_x = K_{x0}(1 - \frac{q_x}{r_x}(e_{1x} + e_{2x})) \underbrace{(1 + \frac{q_y}{r_y}(e_{1y} + e_{2y}))^{\alpha}}_{\text{effect of reduced stock } Y} \quad .$$

Ecological-Economic Model

- Payoff of each fisherman $i, i = 1, 2$ be

$$p_x h_{ix} + p_y h_{iy} - c_{ix} e_{ix}^2 - c_{iy} e_{iy}^2$$

h_{ij} is individual harvest of fisherman i from harvesting j,

- Price p_x depends on supply (linear demand function)

$$p_x = a - bq_x K_{x0}(1 - \frac{q_x}{r_x} E_x)(1 + \frac{q_y}{r_y} E_y)^{\alpha} E_x,$$

$p_y = 0$ - Species y has no market value.

- $c_x = const$ is common knowledge, asymmetry of information on c_y

$$c_{iy} = \begin{matrix} c_L, & 0 \leq \nu \leq 1 \\ c_H, & 1 - \nu. \end{matrix}$$

Only fisherman knows her true c_y, other fisherman and the principal know only distribution.

Ecological-Economic Model

- The principal has complete knowledge of α
- Fishermen are assume $\alpha = 0$ ('pessimistic').

Contract is necessary to induce harvesting *y*!

Question

We look into three cases of regulation and study their implementability

- No regulation on y: BAU single-species regulation
- Two-species fishery and Complete Contract: no asymmetry of information. Principal proposes harvesting of x and y and subsidies according to joint welfare maximization (social optimum, first best)
- Two species-fishery and Contract under information asymmetry: adverse selection problem requires incentive compatibility constraints.

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Single-species regulation

'Business-as-usual' scenario: joint welfare maximisation of the fishermen payoff in the steady state (W_0 is individual payoff)

$$\max_{e_x} W^0 = \left\{ \left(a - bK_{x0}q_x(1 - \frac{q_x}{r_x}2e_x)2e_x \right) K_{x0}q_x(1 - \frac{q_x}{r_x}2e_x)e_x - \frac{c_x}{2}e_x^2 \right\}.$$

e_{x0} is (**unique symmetric equilibrium**) optimal harvesting efforts of species x, and S_x^0 correspondent steady state.

Complete Contract of Two-species Fishery

Two-species management problem and no information asymmetry.
Objective in social optimum

$$\max_{e_{1x},e_{2x},e_{1y},e_{2y}} W^{SO} =$$

$$\begin{cases} 2\left(p_x^{LL}h_{xL}^{LL} - \frac{c_x}{2}e_{xL}^{LL2} - \frac{c_L}{2}e_{yL}^{LL2}\right), \text{ if both LL,} \\ p_x^{LH}(h_{xL}^{LH} + h_{xH}^{LH}) - \frac{c_x}{2}e_{xH}^{LH2} - \frac{c_H}{2}e_{yH}^{LH2} - \frac{c_x}{2}e_{xL}^{LH2} - \frac{c_L}{2}e_{yL}^{LH2}, \text{ if L and H} \\ 2\left(p_x^{HH}h_{xH}^{HH} - \frac{c_x}{2}e_{xH}^{HH2} - \frac{c_H}{2}e_{yH}^{HH2}\right), \text{ if both HH,} \end{cases}$$

and obtain fist-best solution (efforts & transfers)

- e_{xH}^{HH*}, e_{yH}^{HH*}, and t^{HH*}
- e_{xH}^{LH*},e_{yH}^{LH*}, e_{xL}^{LH*}, e_{yL}^{LH*} and t_H^{LH*}, t_L^{LH*},
- e_{xL}^{LL*},e_{yL}^{LL*} and t^{LL*}.

Contract under information asymmetry

Principal's objective becomes maximization of the revenue from the fishing activity minus information rent paid to the fishermen (to reveal their true type)

$$\max_{e_{xH}^{HH}, e_{xH}^{LH}, e_{xL}^{LH}, e_{xL}^{LL}, e_{yH}^{HH}, e_{yH}^{LH}, e_{yL}^{LH}, e_{yL}^{LL}} \Big\{ 2\nu^2 \big((a - bH_x^{LL}) h_{xL}^{LL} - \frac{c}{2} e_{xL}^{LL2} - \frac{c_L}{2} e_{yL}^{LL2} \big) +$$

$$2(1-\nu)^2 \big((a - bH_x^{HH}) h_{xH}^{HH} - \frac{c}{2} e_{xH}^{HH2} - \frac{c_H}{2} e_{yH}^{HH2} \big) +$$

$$2\nu(1-\nu) \big((a - bH_x^{LH}) h_{xL}^{LH} - \frac{c}{2} e_{xL}^{LH2} - \frac{c_L}{2} e_{yL}^{LH2} + (a - bH_x^{LH}) h_{xH}^{LH} - \frac{c}{2} e_{xH}^{LH2} - \frac{c_H}{2} e_{yH}^{LH2} \big)$$

$$-2\nu^2 \big(U_H^{LH}(0) + \frac{\Delta c}{2} e_{yH}^{LH2} \big) - 2(1-\nu)^2 U_H^{HH}(0)$$

$$-2\nu(1-\nu)(U_H^{HH}(0) + \frac{\Delta c}{2} e_{yH}^{HH2} + U_H^{LH}(0)) \Big\}.$$

Contract under information asymmetry

Next we need to take into consideration participation and incentive compatibility constraints (below we shall use notation $\Delta c = c_H - c_L$ and $U(0)$ as out of contract utility, i.e. single species regulation e_x^0)

$$U_L^{LL} \geq U_H^{LH} + \frac{\Delta c}{2} e_{yH}^{LH2},$$

$$U_L^{LL} \geq U_L^{LL}(0)$$

$$U_L^{LH} \geq U_H^{HH} + \frac{\Delta c}{2} e_{yH}^{HH2},$$

$$U_L^{LH} \geq U_H^{LH}(0)$$

$$U_H^{LH} \geq U_L^{LL} - \frac{\Delta c}{2} e_{yL}^{LL2},$$

$$U_H^{LH} \geq U_H^{LH}(0)$$

$$U_H^{HH} \geq U_L^{LH} - \frac{\Delta c}{2} e_{yL}^{LH2},$$

$$U_H^{HH} \geq U_H^{HH}(0).$$

Contract under information asymmetry

In case of 2-player contract $(e_x^{SB}, e_y^{SB}, t^{SB})$

1. Both players efficient (LL), harvesting efforts are efficient (=socially optimal)
$$e_{yL}^{LL,SB} = e_{yL}^{LL*} \text{ and } e_{xL}^{LL,SB} = e_{xL}^{LL*}$$
2. One player is efficient and another inefficient, contract is suboptimal
   - $$e_{yL}^{LH,SB} \geq e_{yL}^{LH*} \text{ and } e_{yH}^{LH,SB} \leq e_{yH}^{LH*},$$
$$E_y^{LH,SB} \leq E_y^{LH,*},$$
   - $$e_{xH}^{LH,SB} = e_{xL}^{LH,SB} \geq e_x^{LH*}.$$
3. Both are inefficient players (HH), harvesting effort to y below SO level and harvest x with higher effort than SO
$$e_{yH}^{HH,SB} \leq e_{yH}^{HH*},$$
$$e_{xH}^{HH,SB} \geq e_{xH}^{HH*}.$$

Numerical Analysis

Table: Model parameters values

Parameter for x	value	Parameter for y	value
K_{x0}	1500	K_y	1000
r_x	0.325	r_y	0.325
q_x	$[0.01, 0.4]$	q_y	$[0.01, 0.4]$
c_x	80	c_y	$[20, 120]$
α	$[0, \infty]$		
a	20		
b	0.1		

In particular, parameters are $q_x = 0.05$, $q_y = 0.05$, $c_H = 120$, $c_L = 20$.

Numerical Analysis

Table: Model results

Regulation	e_{xH}	e_{xL}	e_{yH}	e_{yL}	S_x	S_y	t_H	t_L
Single-species regulation on x	0.812	0.812	–	–	1125.35	1000	–	–
Social Optimum both efficient	–	0.669	–	0.623	1419.81	808.34	–	12.362
one efficient another inefficient	0.707	0.707	0.125	0.750	1331.89	865.359	5.345	10.034
both inefficient	0.769	–	0.167	–	1203.96	948.544	2.364	–
Optimal Contract both efficient	–	0.669	–	0.623	1419.81	808.34	–	12.556
one efficient another inefficient	0.711	0.711	0.070	0.766	1322.45	871.481	4.327	10.668
both inefficient	0.780	–	0.124	–	1183.56	961.861	1.302	–

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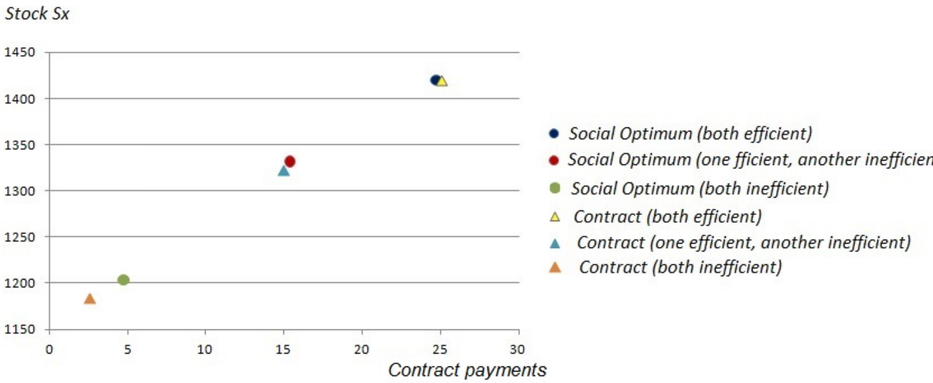

Figure: Steady state stock S_x Vs. Subsidy for harvesting y

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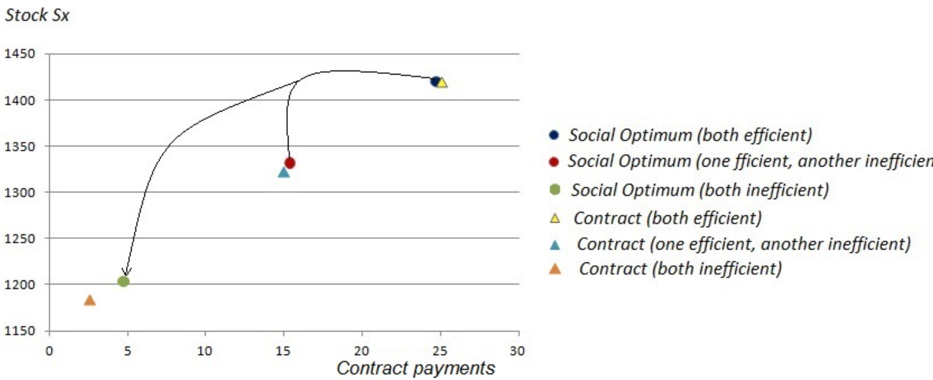
Implementation of social optimum (first best) in asymmetric information setting leads to adverse selection: only social optimum with inefficient players is implementable



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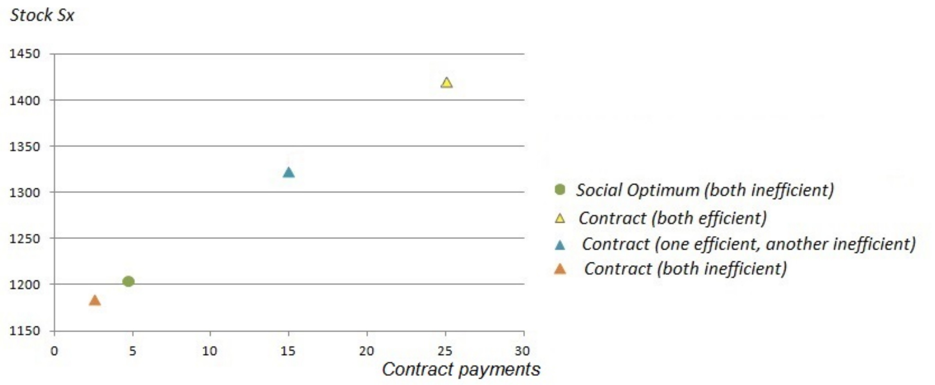

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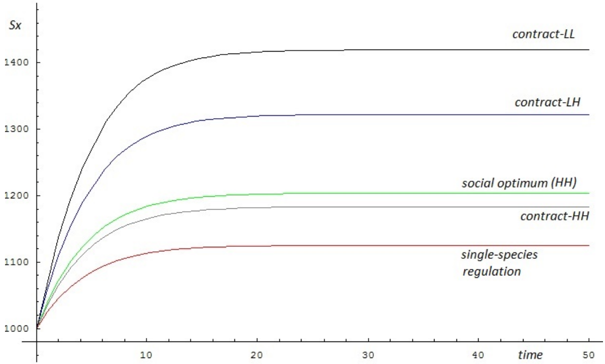

Figure: Stock dynamics of commercial species x in case of contract and social optimum

Conclusion

1. Fishing game with 2 interdependent species and incomplete and uncertain information of harvesting non-commercial species
2. modified Gordon-Schaeffer model
3. Single-species regulation, Social optimum (no information asymmetry) and Contract
4. Adverse selection in harvesting y and misinformation: only inefficient solution!
5. Contract (second-best) leads to close-to-optimal harvesting and regulation and truthful cost structure

Future development:
compare 2-player contract with single-player contract: general vs. exclusive contracting
compare static vs. dynamic contracting