Management strategies for sardines: A game theoretic approach

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February 13, 2013

The broad question to be answered

- Is a cooperative economic strategy between the US, Canada and Mexico sharing a highly commercial species such as the Pacific sardine beneficial for conservation efforts? If so, how?

Outline of the talk

- Motivation
- Game theory basics: Cooperative games, The Cournot model and Nash equilibrium
- Cobb Douglas model
- Some thoughts and conclusion

Sardines

- Epipelagic
- Virtually the only predators of all below them (plankton) and virtually the only prey of the tiers above them (bigger fish, seabirds, marine mammals)
- Maintains a delicate population balance in the wasp-waist ecosystem model

Motivation-History

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- (2012) Oceana-

  Sardine population on verge of crash

  NMFS-

  the Coast-wide harvest rate including Canada and Mexico is less than 15 percent of the biomass; decidedly NOT overfishing.

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Motivation-Bioeconomic models, overlaid on top of biological models

$$\frac{dx}{dt} = F(x) - h(t)$$

- $F(x)$-Natural growth rate of a given population
- $h(t)$-Rate of harvests:
- $h(t)$ depends on the current size of the stock $x = x(t)$ AND the rate of harvesting effort $E = E(t)$
- $h = Q(E, x)$=The production function=$G(x)E$

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- Net economic revenue produced by an input of effort $E\Delta t = [ph - cE]\Delta t = [p - c(x)]h\Delta t = R(x, E)$ where $c(x) = \frac{c}{G(x)}$

Motivation-Optimal Harvest Policy

- $PV = \int_0^\infty e^{-\delta t} R(x, E) dt = \int_0^\infty e^{-\delta t}[p - c(x(t))]h(t)dt$ subject to $x(t) \geq 0$ and $h(t) \geq 0$
- Goal: To maximize the above PV. Optimal control theory
- Quick solution: $\int_0^\infty e^{-\delta t}[p - c(x(t))][F(x) - \dot{x}]dt$ which is of the form: $\int \phi(t, x, \dot{x}) \implies \frac{d\phi}{dx} = \frac{d}{dt}\frac{\partial \phi}{\partial \dot{x}} \implies$
- $F'(x) - \frac{c'(x)F(x)}{p - c(x)} = \delta$

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- Enough of motivation!

Game theory basics

- Consider two countries producing sardines and selling it in the market. They will try to maximize their own Profits=Sales-Cost.
- $\pi_1(q_1, q_2) = RT_1 - CT_1$ and $\pi_2(q_1, q_2) = RT_2 - CT_2$.
- π_i-Profit, RT_i-Total sales, CT_i-Total cost.
- $RT_1 = p(q) * q_1 = [A - b(q_1 + q_2)] * q_1 = Aq_1 - bq_1^2 - bq_1q_2$
- $RT_2 = p(q) * q_2 = [A - b(q_1 + q_2)] * q_2 = Aq_2 - bq_1q_2 - bq_2^2$
- $CT_1 = cq_1, CT_2 = cq_2$. Assumption: Same costs for both countries. Not necessary.

Game theory basics-Nash equilibrium

- $\frac{\partial \pi_1}{\partial q_1} = A - 2bq_1 - bq_2 - c = 0$
- $\frac{\partial \pi_2}{\partial q_2} = A - bq_1 - 2bq_2 - c = 0$
- $q_1 = \frac{A - bq_2^e - c}{2b} = f(q_2)$
- $q_2 = \frac{A - bq_1^e - c}{2b} = f(q_1)$
- Nash equilibrium-Solution in which players strategies represent the best answers to each other, reciprocally. $q_1 = q_1^e$ and $q_2 = q_2^e$ i.e.
- $q_1^* = \frac{A-c}{3b}, q_2^* = \frac{A-c}{3b}$
- $\pi_1 = \pi_2 = \frac{(a-c)^2}{9b^2}$
- NO INCENTIVE TO DEVIATE.

Game theory basics-Nash equilibrium with collusion

- $\pi_T = \pi_1 + \pi_2 = Q(a - bQ - c)$ where $Q = q_1 + q_2$
- $Q^* = \frac{a-c}{2b}$
- If we assume $q_1 = q_2 = \frac{a-c}{4b}$, $\pi_1 = \pi_2 = \frac{(a-c)^2}{8b^2}$
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- Lots of assumptions made: Constant costs, equal quantities should be produced by both countries
- Prices will increase, quantities will decrease under collusion for any general Cournot Oligopoly game.

Game theory basics-A fisheries Cournot duopoly model

- E_i-Effort, q_i-Catches=$f(E_i, X)$,X- Biomass level of sardine
- $\pi_i(E_1, E_2)$=$RT_i - CT_i$
- $\pi_1(E_1, E_2) = [A - b(f(E_1, X) + f(E_2, X)]f(E_1, X) - cE_1$
- $\pi_2(E_1, E_2) = [A - b(f(E_1, X) + f(E_2, X)]f(E_2, X) - cE_2$
- $\pi_T = \pi_1 + \pi_2$
- $\frac{\partial \pi_T}{\partial E_1} = \frac{\partial \pi_T}{\partial E_2} = 0$

Game theory basics-Implications

- Aggregate fishing effort is expected to reach a lower level than the sum of the reached levels for each individual solution.
- Costs of fishing expected to be lower.
- Market price higher, aggregate rent higher.
- STOCK MANAGEMENT MORE COMPATIBLE WITH CONSERVATIVE OBJECTIVES!

The Munro model

- Optimal equilibrium biomass:
  $\delta = F'(x^*) - \frac{c'(x^*)F(x^*)}{p-c(x^*)} = \frac{\frac{d}{dx^*}[p-c(x^*)F(x^*)]}{p-c(x^*)}$

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- Own rate of interest=Marginal sustainable net return from the fishery divided by the supply price of the resource=Social rate of discount
- Equilibrium Harvest policy: $h^*(t) = F(x^*)$
- Optimal approach path to x^*, the steady state solution, model is linear in the control variable h. Optimal approach:

$$\begin{aligned} h^*(t) &= h_{max} \text{ whenever } x(t) > x^* \\ &= h_{min} \text{ whenever } x(t) < x^* \end{aligned}$$

The Munro model: Inconsistent view of δ

- $\delta_1 < \delta_2 < \infty$.
- Suppose, therefore, the two countries contemplate a binding agreement.
- Denote $\alpha =$Country 1's harvest share $\implies (1-\alpha) =$ Country 2's harvest share.
- $PV_1 = \int_0^\infty e^{-\delta_1 t}\alpha[p - c(x)]h(t)dt$
- $PV_2 = \int_0^\infty e^{-\delta_2 t}(1-\alpha)[p - c(x)]h(t)dt$

The Munro model: Inconsistent view of δ

- Let β be a bargaining parameter- EstablishES tradeoff between management preferences of two countries.
- Nash's two person cooperative games, no side payments, payoffs non-transferable
- Maximize $\beta PV_1 + (1 - \beta) PV_2 \quad 0 \leq \beta \leq 1$

The Munro model: Inconsistent view of δ

- Threat point: π^0 and θ^0. Prospective payoffs for a two person non-cooperative game
- Nash: Unique solution to maximize $(\pi^* - \pi^0)(\theta^* - \theta^0)$, π^* and θ^* are the solution payoffs
- E.g. $\beta = \frac{1}{2}$ implies equal weight to the two countries management preferences.
- A basic framework that is applied to current negotiations of shared resources between different countries (Sumaila 1997, 1999), Suris J.C.(2003)(Regulation of Iberoatlantic sardine), Armstrong C.(Arcto Norweigian cod)

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- Competitive behavior of agents might only be due to short term interests.
- Discrete model with finite time horizon. Usually a useful thing for agreement between countries.

A proposed Cobb Douglas model

- $Y_{i,t} = q_i E_{i,t}^{\alpha i} X_T^{1-\alpha i} = q_i L_{i,t}^{\alpha i} X_t$
- X_t-spawning biomass in year t.
- $Y_{i,t}$-Number of catches fished by the fleet of country i in year t
- q_i- Catchability coefficient
- $E_{i,t}$-Effort of country i in year t.
- $L_{i,t} = (\frac{E_{i,t}}{X_t})$

Cooperative scenario

- For a logistic growth function $X_{t+1} - X_t = aX_t - bX_t^2 - (Y_{1,t} + Y_{2,t})$
- p_i - Price per ton fished in country i, w_i - Cost per unit effort,δ_i - Discount factor in each country

$$Max_{E_1,E_2} \sum_{t=0}^{T-1} \beta\delta_1^t[p_1 q_1 L_{1,t}^{\alpha 1} X_t - w_1 E_{1,t}] +$$

$$(1-\beta)\delta_2^t[p_2 q_2 L_{2,t}^{\alpha 2} X_t - w_2 E_{2,t}]$$

subject to

$$X_{t+1} - X_t = aX_t - bX_t^2 - (q_1 L_{1,t}^{\alpha 1} X_t + q_2 L_{2,t}^{\alpha 2} X_t)$$

$$0 \leq E_1(t) \leq E_1 max$$

$$0 \leq E_2(t) \leq E_2 max$$

$$X(t) \geq 0$$

$$X(0) = X_0$$

Competitive scenario

$$Max_{E_i} \sum_{t=0}^{T-1} \delta_i^t [p_i q_i L_{i,t}^{\alpha i} X_t - w_i E_{i,t}]$$

subject to

$$X_{t+1} - X_t = aX_t - bX_t^2 - (q_1 L_{1,t}^{\alpha 1} X_t + q_2 L_{2,t}^{\alpha 2} X_t)$$

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Case of perfect information-Fishing sectors from each country decide optimal exploitation policy and also to decision made by second country about fishing effort they are going to apply.

Myopic competition

- Respective national fleets ONLY try to maximize their income in the short term, without competitor's performance or biological restrictions
- Equalization of costs and marginal revenues
- $\alpha_i p_i q_i L_{i,t}^{\alpha i-1} = w_i$

The final idea

- Nash cooperative game strategy: Ideally want to use β from the negotiation process that maximizes $(\pi^* - \pi^0)(\theta^* - \theta^0)$.
- No rational agent will want to accept any payment from the game smaller than his threat point.
- Side payments not addressed

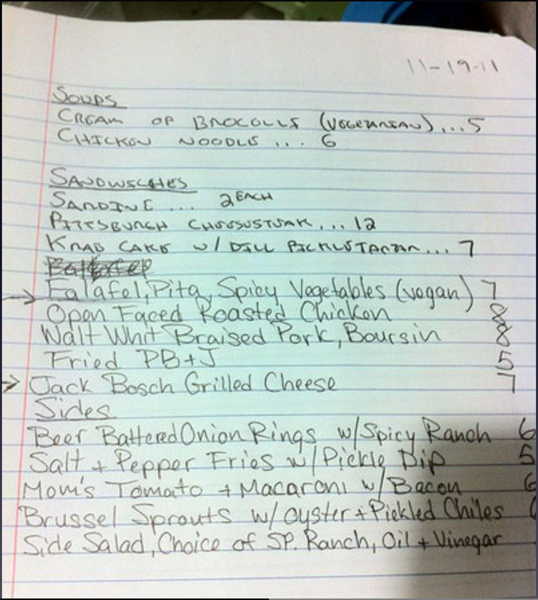
The Pacific sardine (Sumaila 2012)

- A three country game. Mexcio, US and Canada
- Currently no cooperation exists.
- Mexico with US and Canada, myopic competition
- Canada and the US; non-cooperation
- Stocks are assessed separately; 2013 HCR (Harvest Control Rules) assume 87 percent sardine stock in North American waters and 13 percent in Mexican waters.

What I need and would like to do

- Data- Sardine catches and stock evolution for the 3 countries, Fishing days across time, estimates for CPUE, Discount rate (a fairly linear trend accounting for inflation across time), fish prices (can estimate average price per landed ton) and effort costs.
- Apply the model presented above to these data; Use production model similar to the recent paper by Sumaila; based on a production function based on climate indicators.
- Thanks! Prof. Vince Gallucci for thinking this will be a cool problem to work on! CQS for all the funding.

Questions


11-19-11
SOUPS
CREAM OF BROCOLLI (VEGETARIAN)...5
CHICKEN NOODLE ... 6
SANDWICHES
SARDINE ... 2 EACH
PITTSBURGH CHEESESTEAK ... 12
KRAB CAKE w/ DILL PICKLE TARTAR ... 7
Falafel, Pita, Spicy Vegetables (vegan) 7
Open Faced Roasted Chicken 8
Walt Whit Braised Pork, Boursin 8
Fried PB+J 5
Jack Bosch Grilled Cheese 7
Sides
Beer Battered Onion Rings w/Spicy Ranch 6
Salt + Pepper Fries w/Pickle Dip 5
Mom's Tomato + Macaroni w/Bacon 6
Brussel Sprouts w/ Oyster + Pickled Chiles
Side Salad, Choice of SP. Ranch, Oil + Vinegar