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The Impact of Environmental Variability on Fishers' Harvest Decisions in Chile

Using a Multi-Species Approach

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Big picture

- Marine resource distribution and abundance is changing due to climate variability, with heterogenous spatial effects (Poloczanska, Brown, Sydeman et al., 2013).
- Harvest levels would be affected (Quezada, Tommasi, Frawley et al., 2023), as well as price and value of catches, fishing costs, fishers' incomes, among others

Introduction

Research question

How fishing decisions, aggregate catch levels, and the price of marine resources will be affected under different climatic scenarios in the multispecies small pelagic fishery (SPF) in Chile.

- How do fishers **substitute between species**?
- Contribute to the sparse local multi-species economic modeling literature in Chile
  - See Peña-Torres, Dresdner, and Vasquez (2017) for ENSO effects in Jack Mackerel fishery using discrete choice models.

#

Why a Multi-Species Model?

- Diversification improves income stability and climate resilience (Kasperski and Holland, 2013; Finkbeiner, 2015)
- Fishers respond to change by:
  - Maintaining the current strategy
  - **Reallocating effort to other species/areas (Gonzalez-Mon, Bodin, Lindkvist et al., 2021)**
  - Exiting the fishery (Powell, Levine, and Ordonez-Gauger, 2022)

Introduction

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Relevance

- Under multispecies harvesting is not straighforward to study fisher harvest decisions
  - Responses to availability vary by (i) port infrastructure, (ii) market access, and (iii) regulations (Powell, Levine, and Ordonez-Gauger, 2022)
  - Different fishers, different choices (Jardine, Fisher, Moore et al., 2020; Zhang and Smith, 2011)
- Understand fishers' adaptive capacity
  - Inform climate-resilient fisheries policies in Chile

Case Study: Chile's Small Pelagic Fishery (SPF)

- Anchoveta, Jack mackerel, Sardine
- ~94% of national catch (SUBPESCA, 2020)
- Climate variability will impact:
    - Species composition
    - Prices
    - Trip cost
    - Total annual trips
    - Catch levels

Methodology Overview

Based on Kasperski (2015):

1. Estimate stock dynamics
2. Estimate trip-level costs
3. Estimate annual trips
4. Estimate inverse demand
5. Simulate climate change effects on profits/harvest

Data Sources

Requested (2012–2024)

- Stock abundance
- Annual landings
- Trip-level data
- Ex-vessel prices

Retrieving from Climate Model Intercomparison Project (CMIP)

- Sea Surface Temperature (historical and projections)
- Chlorophyll (historical and projections)
- Salinity (historical and projections)
- Wind Speed (historical and projections)
- Wave height (historical and projections)
- Precipitations (historical and projections)

Note: Requested in lower resolution to Fabian Tapia (Oceanographic, UdeC)

Data Sources

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To Be Requested

- Crew wages (maybe INE?)
- Fuel prices
- Vessel permits
- TAC
- Quota prices (auction/secondary market?)

Model 1: Stock Dynamics

$$x_{i,y+1} + h_{iy} = \underbrace{(1 + r_i)x_{iy} + \eta_i x_{iy}^2}_{R_i(x_{iy})} + \underbrace{\sum_{j \neq i}^{n-1} a_{ij} x_{iy} x_{jy}}_{I_i(x_y)} + \rho_i Env_{iy} + \varepsilon_{iy} \quad i = 1, \ldots, n$$

- where:
  - x_{iy} is the fish stock by species $i = 1, \ldots, n$ in year y, n is the total number of species,
  - h_{iy} is the annual harvest of species i on year y,
  - r_i is the intrinsic growth rate of the resource i,
  - η_i is a density-dependent factor related to the carrying capacity,
  - α_{ij} are the interaction parameters between species.
  - Env_{iy} includes environmental covariates (SST and chlorophyll)
- System of n growth equations can be estimated simultaneously using SUR (¿endogeneity?)
  - SST and CHL improves model (F = 1.908; p-value = 0.07).

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Base model

$$C_{vg} = \sum_{i=1}^{2n+M+k} \alpha_{g,\mathbf{x}_i} \mathbf{X}_{ivg} + \frac{1}{2} \sum_{i=1}^{2n+M+k} \sum_{j=1}^{2n+M+k} \alpha_{g,\mathbf{x}_i \mathbf{x}_j} \mathbf{X}_{ivg} \mathbf{X}_{jvg}$$

where:

- $C_{vg} = w z_{vg}^{*}$ is the total cost incurred by vessel $v = 1, \ldots, V_g$ conditional on gear used $g = 1, \ldots, G$:
  - z_{vg}^{*} is the optimal quantity of input used, (e.g., crew members, time spent at sea, distance traveled?)
  - w is a matrix of variable input prices,
- $\mathbf{X}_{vg} = [w; h_{vg}; x; Z_v]$ is a matrix of explanatory variables, and $\mathbf{X}_{ivg}$ represents the ith column of the $\mathbf{X}_{vg}$:
  - h_{vg} is a matrix of harvest quantities,
  - x is a matrix of given stock levels of the species of interest, and
  - Z_v is a matrix of given vessel characteristics.

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Model with the environment

To link this function to climate variability

- Include additional environmental variables Env to $\mathbf{X}_{vg}$
  - e.g., wind intensity and wave conditions in each trip at the harvest location, upon data availability.
- Therefore, the augmented X_{vg} matrix becomes $\mathbf{X}_{vg}^{'} = [w; h_{vg}; x; Z_v; Env]$.
- The model can be estimated with **SUR**.

Model 3: Total Annual Trips

The number of trips a vessel will take in a given year for each gear type used is assumed to follow a Poison distribution Kasperski (2015):

$$Pr\left[T^*_{vgy} = t_v\right] = \frac{exp^{-exp(U^{'}_{vg}\beta_g)} exp(U^{'}_{vg}\beta_g)^{t_v}}{t_v!}$$

where

- $U_{vg} = [p, w, h_{vg}, \bar{q}, Z_{vg}]$ is a matrix of explanatory variables,
- β_g is a vector of coefficients to be estimated,
- t_v is the number of trips taken by vessel v using gear type g in year y, and
- $\bar{q}$ is the annual quota level.

Additionally, we can add the accumulation of *bad weather days?* as an explanatory variable to incorporate weather conditions into this decision, thus: - $U_{vg} = [p, w, h_{vg}, \bar{q}, Z_{vg}, Env]$

- Other variables? e.g., state dependency?

Model 4: Inverse Demand

The price of each species is modeled using an **inverse demand model**. The price of a species i in year y is the following:

$$p_{iy} = \sum_{j}^{n} \gamma_j p_{j,y-1} + \gamma_{h_i} h_{iy} + x'\beta + \epsilon_{iy}, \quad i = 1, \ldots, n, \ j = 2, \ldots, n, i \neq j.$$

- The system can be estimated using 2SLS, instrumenting harvest with climate variables and other cost shifters.
  - Undergrad student analyzing the option to estimate a supply-demand system with 3SLS for each species (6 equations simultaneously?)
- Other variables for the demand?
- Endogeneity of substitute prices?

Maybe then see if we need to estimate a AR(1) model?? (**HELP LEO!!!**):

$$p_{iy} = \gamma_i p_{i,y-1} + \sum_{j}^{n} \gamma_j p_{j,y-1} + \gamma_{h_i} h_{iy} + x'\beta + \epsilon_{iy}$$

Integration and Simulation

Use models parameters to:

- Conduct numerical optimization for different climate scenarios
- Obtain the optimal **harvest** and **quota** conditional on climate scenario
- Evaluate **profits** and **species substitution**
- I need future projection for climate/environmental variables (?)

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Vessel maximization problem

In each year, a vessel maximizes profits by choosing their optimal number of trips T_g and harvest levels per trip $h_{g\tau}$ given a gear type:

$$\max_{h_{gt},T_g} \quad \pi_{vgt} = \sum_{\tau=t}^{T_g} \rho^{\tau} \left\{ P(h)h_{g\tau} - C_g(h_{g\tau}|w, x, Z, Env) \right\} \quad \tau = t, \ldots, T_g$$

$$\textbf{s.t} \quad q_{g,t+1} = \omega * \bar{q} - \sum_{t=1}^{t} h_{gt} \geq 0, \quad t = 1, \ldots, T-1, \quad g = 1, \ldots, G$$

- where:
  - ρ is the intra-annual discount factor,
  - ω is a vector of shares of $\bar{q}$, and
  - $h_{lt} = 0$ for all $l \neq g$.

Numerical optimization

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Some considerations

- The vector of shares is obtained from historical data on harvest.
- The optimal profit from the maximization problem is $\pi^*_{vgy}(p, w, x, Z, \bar{q}, \omega, Env)$,
  - h^*_{vgty} is the optimal harvest per trip.
  - T^*_{vgy} optimal total number of trips.
- Optimal quota level, per year and by species, is obtained by solving the social-planner optimization problem to maximize the net value of the fishery

Expected Results

- Climate variability affects:
    - **Stock** dynamics
    - **Fishing costs**
    - **Trip frequency**
- Catch composition shifts with climate
- Localized market effects

¡Muchas gracias!

¿Preguntas?

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