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

Using a Multi-Species Approach

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Encuentro EfD Chile 2025

Introduction

Big picture

- Marine resource distribution is changing due to climate variability (Poloczanska, Brown, Sydeman et al., 2013).
- Thus, harvest levels would be affected by climate variability (Quezada, Tommasi, Frawley et al., 2023)

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)

Relevance

- Under multispecies harvesting is not straighforward to study fisher harvest decisions
  - Responses to availability vary by (i) port infrastructur, (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
- 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.

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

Research Questions

- How will **fishing decisions, catch levels, and prices** evolve under different climate scenarios?
- How do fishers **substitute between species**?

Hypotheses

- Reduced availability → Switch if expected revenue > expected cost in other fishery
- Otherwise → Decrease effort or exit
- Behavior is **heterogeneous**:
    - Geography
    - Gear type (Reimer, Abbott, and Wilen, 2017)

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

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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

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

- 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:

- $C_{vg} = wz^*_{vg}$ 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.

Model 2: Trip-Level Costs

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

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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

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

¡Muchas gracias!

¿Preguntas?

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