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

Using a Multi-Species Approach

Felipe J. Quezada-Escalona

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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 (Sumaila, Cheung, Lam et al., 2011)

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Research question

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

- How do fishers **substitute between species**?
- Contribute to the limited local literature on multi-species economic modeling in Chile
  - Understand fishers' adaptive capacity helps to inform climate-resilient fisheries policies in Chile
  - See Peña-Torres, Dresdner, and Vasquez (2017) for ENSO effects in Jack Mackerel fishery using discrete choice models.
- We will focus in **climate variability** to estimate short-run responses.
  - i.e., climate change effect without adaptation (Auffhammer, 2018)

Why a Multi-Species Model?

- Diversification is a good strategy:
  - Improves income stability and climate resilience (Kasperski and Holland, 2013; Finkbeiner, 2015)
- Fishers respond to environmental variability 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)
- 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)

Chile's Small Pelagic Fishery (SPF)

Some facts

- Mainly composed by anchoveta, Jack mackerel, Sardine
- ~94% of national catch (SUBPESCA, 2020)
- Mostly harvested with purse-seiners
- In the Central-South (CS) region (Valparaiso-Los Lagos) all three species play a major role.
- SPF have been used primarily for fishmeal and fish oil production [@Pena-Torres2017-gn] (~85% of jack mackerel for reduction)

Regulations

- Quota (TAC); divided between the small-scale and indutrial sector
- Industrial sector operates under ITQ
- RAE (*Regimen Artesanal de Extracción*) in some areas for small-scale fishery
  - Allocates regional quota to area or fishermen organization (i.e., catch shares)
- Anchoveta and sardine are regulated as a mixed-species fishery

Status of the stocks (CS)

- Anchoveta:
  - Collapsed until 2018,
  - Overexploited in 2019, and has
  - Since 2020, within MSY limits.
- Sardine:
  - Within MSY levels, except in 2021 and 2023 (overexploited)
- Jack mackerel:
  - Overexploited until 2018, then within MSY limits.

Methodology Overview

Based on Kasperski (2015):

1. Econometrics models
    - Estimate stock dynamics
    - Estimate trip-level costs
    - Estimate annual trips
    - Estimate inverse demand
2. Simulations
    - Obtain optimal harvest and quota levels
    - Simulate climate change effects on profits, harvest and prices.

Data Sources

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- From IFOP:
  - Trip-level data
  - ID, departure and arrival times, vessel capacity, fleet and gear type, ports of departure and landing, haul timing and location, species, retained catch.
  - Annual stock abundance
  - Monthly landings by port.
  - Prices paid by processing plants (IFOP surveys; month-region)

Data Sources

Environmental covariates:

From E.U. Copernicus Marine Service Information:

- Global Ocean Physics Reanalysis
- Daily salinity, sea surface temperature, and current speed and direction.
- Global Ocean Hourly Reprocessed Sea Surface Wind and Stress from Scatterometer and Model dataset
    - Hourly wind speed and direction at the surface
- Global Ocean Colour dataset
    - Chlorophyll-a concentrations were obtained from the .

Information:

- 2012–2024
- Chilean Exclusive Economic Zone (EEZ) between 32°S and 41°S
- Coarsest resolution: ~ 10km

Data Sources

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To be requested

- Average wage pay to crew member per hour (available?)
- Diesel cost.
- Permits by vessels
- Quota prices (auction or secondary markets, if available)
    - Captures forward-looking behavior and information [@Birkenbach2024]. @reimer2022structural
    - Simplify the dynamic model to a static one.
- Quota by area/fishing organization for small-scale sector, and ITQ for industrial (by vessel?)
    - Information about Reallocations of quotas

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Data for projections

OracleBio:

- Only decadal (e.g., 2040–2050) projections
- Different climate scenarios
- SST, salinity, currents and chlorophyll (4km resolution)
- No winds; CMIP6 for winds? (~100 km).

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
  - SST and CHL improves model (F = 1.908; p-value = 0.07).

Model 2: Trip-Level Costs

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

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,
- $\mathbf{X}^{'}_{vg} = [w; h_{vg}; x; Z_v; Env]$ 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.
  - Env is a matrix of **environmental covariates**
  - e.g., wind intensity and wave conditions in each trip at the harvest location? (or within a port radius?)

Model 3: Total Annual Trips

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

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

where

- $U_{vg} = [p, w, h_{vg}, \bar{q}, Z_{vg}, Env]$ 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.
- Env include variables that reflect annual weather conditions
  - Accumulation of *bad weather days*? or *number of storms*?
- Other variables? State dependency?

Model 4: Inverse Demand

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The price of each species is modeled using an Inverse Almost Ideal Demand System (IADS). The price of a species i in year y is the following:

$$\ln p_{iy} = \sum_{j}^{n} \gamma_j \ln h_{j,y} + \gamma_H \ln H_y + \gamma_{FM} \ln P_y^{\text{FishMeal}} + \epsilon_{iy}$$

where:

- $H_y = \sum h_{j,y}$
- P_y^{FishMeal} is the fish meal world price

Harvest may be endogenous

- Three Stage Least Squares (3SLS) procedure,
- $h_{j,y}$ instrumented by variables that affect supply function such as *SST*, *Chl*, and fuel prices.

Two undergrad students working on this module for their thesis...

- Results by July 2026
- If they have time, analyze long-run and short-run dynamics with a VEC

Integration and Simulation

Use models parameters to:

- Obtain the optimal **harvest** and **quota** using historical data
- Conduct numerical optimization to obtain optimal **harvest** and **quota** conditional on climate scenario.
- Evaluate **profits** and **species substitution**

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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:

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

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

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

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
- Effect on prices, at least on the short-run

Preliminary results

WORK ON THIS!

¡Muchas gracias!

¿Preguntas?

Felipe J. Quezada-Escalona

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felipequezada.com

References

Auffhammer, M. (2018). "Quantifying economic damages from climate change". In: *Journal of Economic Perspectives* 32.4, pp. 33-52.

Birkenbach, A. M., M. Lee, and M. D. Smith (2024). "Counterfactual Modeling of Multispecies Fisheries Outcomes under Market-Based Regulation". In: *Journal of the Association of Environmental and Resource Economists* 11.3, pp. 755-796. DOI: 10.1086/727356. eprint: https://doi.org/10.1086/727356.

Finkbeiner, E. M. (2015). "The role of diversification in dynamic small-scale fisheries: Lessons from Baja California Sur, Mexico". In: *Glob. Environ. Change* 32, pp. 139-152.

Gonzalez-Mon, B., Ö. Bodin, E. Lindkvist, et al. (2021). "Spatial diversification as a mechanism to adapt to environmental changes in small-scale fisheries". In: *Environ. Sci. Policy* 116, pp. 246-257.

Jardine, S. L., M. C. Fisher, S. K. Moore, et al. (2020). "Inequality in the Economic Impacts from Climate Shocks in Fisheries: The Case of Harmful Algal Blooms". In: *Ecol. Econ.* 176, p. 106691.

References

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Kasperski, S. (2015). "Optimal Multi-species Harvesting in Ecologically and Economically Interdependent Fisheries". In: *Environ. Resour. Econ.* 61.4, pp. 517-557.

Kasperski, S. and D. S. Holland (2013). "Income diversification and risk for fishermen". En. In: *Proc. Natl. Acad. Sci. U. S. A.* 110.6, pp. 2076-2081.

Peña-Torres, J., J. Dresdner, and F. Vasquez (2017). "El Niño and Fishing Location Decisions: The Chilean Straddling Jack Mackerel Fishery". In: *Mar. Resour. Econ.* 32.3, pp. 249-275.

Poloczanska, E. S., C. J. Brown, W. J. Sydeman, et al. (2013). "Global imprint of climate change on marine life". En. In: *Nat. Clim. Chang.* 3.10, pp. 919-925.

Powell, F., A. Levine, and L. Ordonez-Gauger (2022). "Climate adaptation in the market squid fishery: fishermen responses to past variability associated with El Niño Southern Oscillation cycles inform our understanding of adaptive capacity in the face of future climate change". En. In: *Clim. Change* 173.1-2, p. 1.

References

Quezada, F. J., D. Tommasi, T. H. Frawley, et al. (2023). "Catch as catch can: markets, availability, and fishery closures drive distinct responses among the U.S. West Coast coastal pelagic species fleet segments". En. In: *Can. J. Fish. Aquat. Sci.*. Just-IN.

SUBPESCA (2020). *Informe Sectorial de Pesca y Acuicultura 2019*. Accessed: 02-04-2025. URL: https://www.subpesca.cl/portal/618/articles-106845_documento.pdf.

Sumaila, U. R., W. W. Cheung, V. W. Lam, et al. (2011). "Climate change impacts on the biophysics and economics of world fisheries". In: *Nature climate change* 1.9, pp. 449-456.

Zhang, J. and M. D. Smith (2011). "Heterogeneous Response to Marine Reserve Formation: A Sorting Model approach". In: *Environ. Resour. Econ.* 49.3, pp. 311-325.