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

## Using a Multi-Species Approach

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# Introduction

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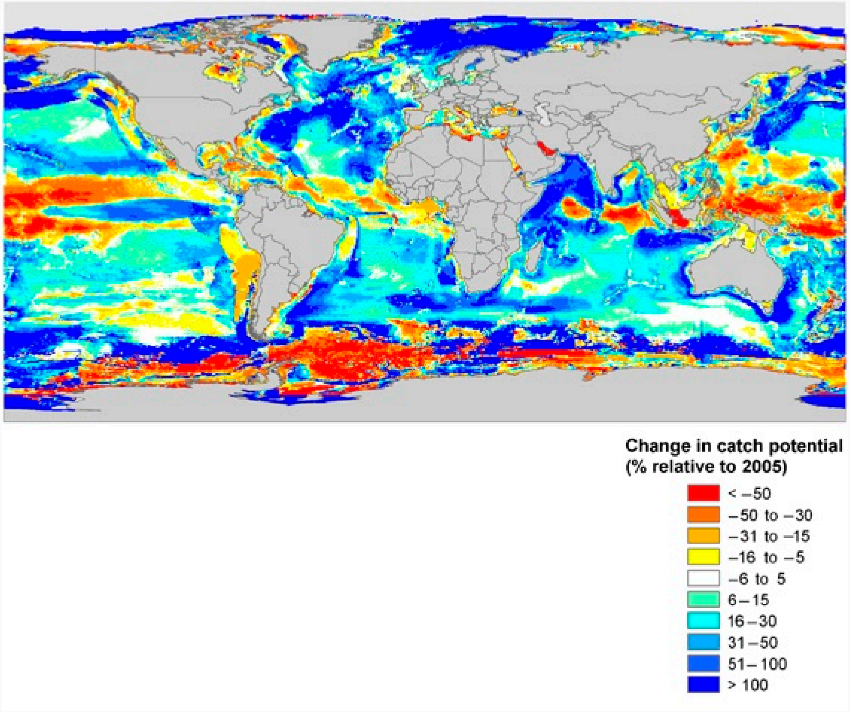
- Marine resource distribution and abundance is changing due to climate variability, with heterogenous spatial effects (Poloczanska, Brown, Sydeman et al., 2013; Sumaila, Cheung, Lam et al., 2011).
- Harvest levels would be affected (Quezada, Tommasi, Frawley et al., 2023),
    - Prices and value of catches, fishing costs, fishers' incomes, among others (Sumaila, Cheung, Lam et al., 2011)




**Source:** Cheung, Lam, Sarmiento et al. (2010)

# Introduction

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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 and climate variability in Chile (e.g., Peña-Torres, Dresdner, and Vasquez (2017))
- Understand fishers' adaptive capacity helps to inform climate-resilient fisheries policies
- We will focus in **climate variability** to estimate short-run responses.
  - *i.e.*, climate change effect without adaptation (Auffhammer, 2018)
  - Upper-bound estimates

# Chile's Small Pelagic Fishery

# Chile's Small Pelagic Fishery (SPF)

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## 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 (Peña-Torres, Dresdner, and Vasquez, 2017) (~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

# Chile's Small Pelagic Fishery (SPF)



## Status of the stocks (CS)

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

# Methods and data

# Methodology Overview



Based on Kasperski (2015):

- Econometrics models
  - Estimate stock dynamics
  - Estimate trip-level costs
  - Estimate annual trips
  - Estimate inverse demand
- Use parameters to:
  - Obtain the optimal **harvest** and **quota** conditional on climate variables.
  - Simulate the effects on harvest, prices and **profits**, and **species substitution** of different climate scenarios.

# Data Sources

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## Harvest and biomass data

From IFOP (2012-2025):

- 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 biomass by macro region and species (e.g. south-central Chile) -- (1999-2025)
- Monthly landings by port/species.
- Prices paid by processing plants (IFOP surveys; month-region)

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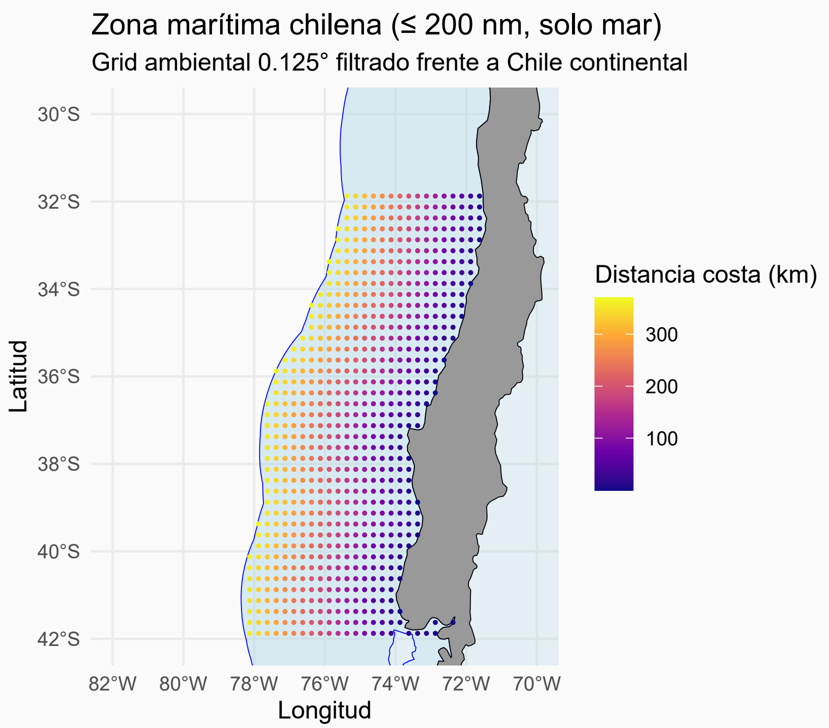
## Environmental covariates

For the period 2000-2025:

- Daily salinity, sea surface temperature, and current speed and direction (E.U. Copernicus Marine Service Information, 2025a)
- Hourly wind speed and direction at the surface (E.U. Copernicus Marine Service Information, 2025b)
- Chlorophyll-a concentration (E.U. Copernicus Marine Service Information, 2025c)



# Data Sources

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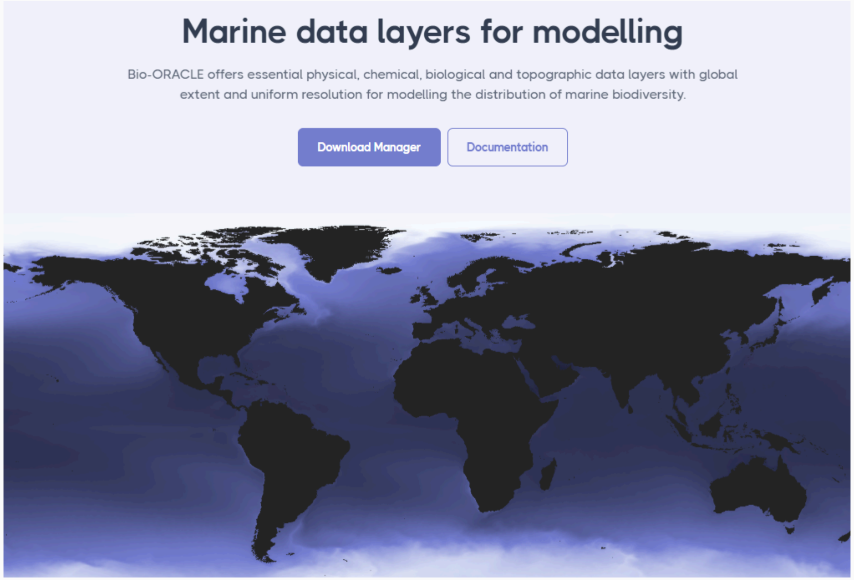
## To be requested

- 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 (Birkenbach, Lee, and Smith, 2024).
  - Simplify the dynamic model to a static one (Reimer, Abbott, and Haynie, 2022).
- Quota by area/fishing organization for small-scale sector, and ITQ for industrial (by vessel?)

## Data for projections

**Bio-ORACLE**

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



# Econometrics models

# 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 $i$,
- $\eta_i$ is a density-dependent factor related to the carrying capacity,
- $\alpha_{ij}$ are the interaction parameters between species.
- $Env_{iy}$ includes year–macroregion averages of **environmental covariates** (SST and chlorophyll-a).

The system of $n$ growth equations can be estimated simultaneously using SUR

# 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 $g = 1, \ldots, G$ -- Mostly purse seiners!

- $w$ is a matrix of variable input prices.
- $z^*_{vg}$ is the optimal quantity of input used
  - Crew members?
  - Time spent at sea?
  - Distance traveled?
- $\mathbf{X}^{'}_{vg} = [w; h_{vg}; x; Z_v; Env]$ is a matrix of explanatory variables:
  - $Env$ is a matrix of **environmental covariates** (e.g., wind intensity and wave conditions in each trip)

# Model 3: Total Annual Trips

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The number of trips a vessel will take in a given year 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,

- $t_v$ is the number of trips taken by vessel $v$ using gear type $g$ in year $y$
- $Env$ include variables that reflect **annual weather conditions**
  - Accumulation of *bad weather days*?
  - *Number of storms*?

# Model 4: Inverse Demand

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The price of each species is modeled using an Inverse Almost Ideal Demand System (IAIDS). The log of the price $p_{iy}$ 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:

- $H_y = \sum h_{j,y}$
- $P_y^{\text{FishMeal}}$ 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.

# Preliminary results

# Is there any subtitution?

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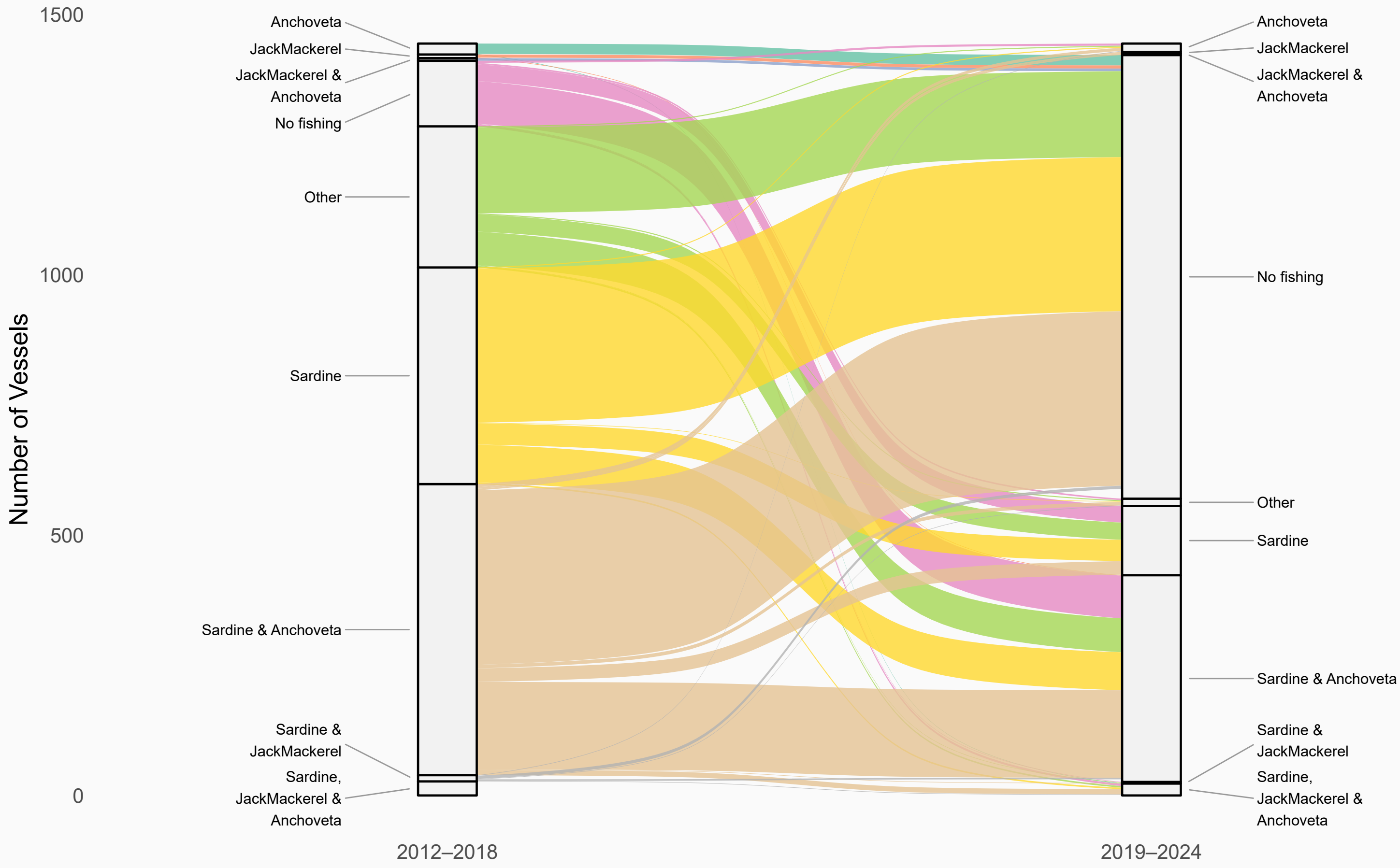
## Small-scale vessels



# Is there any subtitution?

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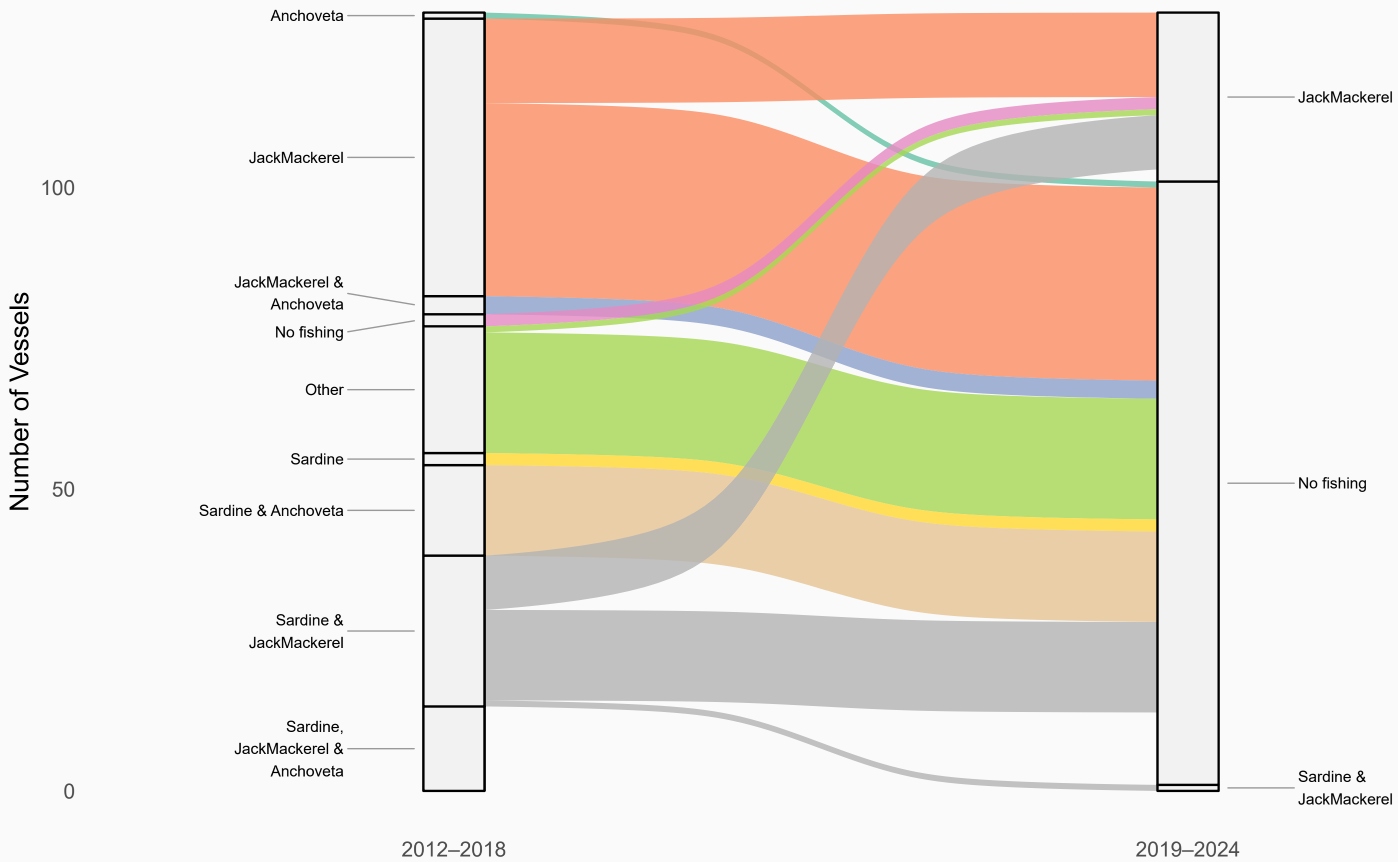
## Industrial vessels



# Stock dynamics

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**Seemingly Unrelated Regression (SUR) estimates of biomass dynamics for small pelagic species in Central–Southern Chile.**

| | Species | | |
|---|---|---|---|
| | *Sardine* | *Anchoveta* | *Jack mackerel* |
| Biomass dynamics | | | |
| Constant | 23.781*** | 10.355*** | 25.891*** |
| Biomass (t) | 0.353* | 1.260*** | 1.035*** |
| Biomass sq (t) | -0.011 | -0.209*** | -0.022** |
| Environmental effects | | | |
| SST | -12.377 | -4.985 | 5.168 |
| (SST) sq | 52.233* | -2.526 | -46.039 |
| Chlorophyll-a | 70.441** | -6.189 | -15.631 |
| Chlorophyll-a sq | 155.277 | 59.220 | 438.550 |
| Cross-species interactions | | | |
| Sardine × Jack mackerel | 0.012 | - | -0.008 |
| Sardine × Anchoveta | 0.017 | -0.010 | - |
| Anchoveta × Jack mackerel | - | 0.011 | 0.045 |
| Model fit | | | |
| R-squared (Adj.) | 0.516 | 0.279 | 0.732 |

Entries are coefficients; significance: * p<0.10, ** p<0.05, *** p<0.01. Quadratic terms shown with "sq"; interactions use ×.

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

# What's Next?



- Finish biomass estimations
- Start soon with total annual trips
  - Hopefully, a short paper can come out of that work
- Two undergraduate students are working on the inverse demand (i.e., price) module for their theses
  - Results expected by July 2026
  - If time allows, they will also analyze long-run and short-run dynamics using a VEC model
  - Plan to write a paper based on their dissertations

# ¡Muchas gracias!

## ¿Preguntas?

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# Appendix A: Numerical optimization

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