Is Demand Reduction Enough to Rebuild Global Fisheries?

Anouch Missirian - with Olivier Deschênes, Christopher Costello, Gavin McDonald (UCSB), Mike Melnychuk (MSC)

May 22nd, 2024

Today's talk

1. Oceans, Biodiversity, and the Economy: A Broad Motivation
2. The Paper in a Nutshell
3. Data
4. Empirical strategy
5. Results: IV estimation and simulations
6. Conclusions

The Central Banker and the Sea

Oceans and Fisheries: What's in it for economists?

From an intellectual point of view:

- fisheries are the poster child of renewable resource economics;
- oceans and fish stocks cover the continuum of property rights from monopoly to full open access;
- in particular oceans and fisheries have served as playground for implementation/study of common pool resource management (Ostrom, 1990).

Oceans and Fisheries: What is so interesting to an economist?

Oceans cover about 70% of the surface of the Earth.

They exert considerable influence on:

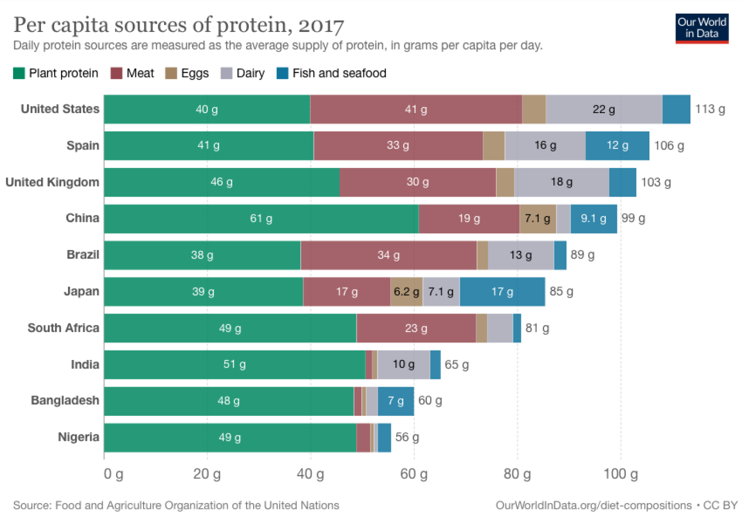
- the climate (heat storage and global circulation);
- our diets (marine fisheries, aquaculture);
- international trade;
- employment and livelihoods in coastal regions and beyond.

As such they feature prominently in heated international disputes, local policy debates.

The threats they currently face are commensurate with their size and importance: changing climate, resource extraction, habitat degradation.

And we know so little about them.

Fisheries: what's the big deal?



Fisheries: what's the big deal?

"Fisheries and aquaculture provide livelihoods to around 820 million people worldwide." (FAO)

"Over 58 million people are engaged in the primary sector of capture fisheries and aquaculture. Of these, approximately 37% are engaged full time, 23% part time, and the remainder either occasional fishers or of unspecified status. Over 15 million are working full-time on board fishing vessels." (ILO)

Satellites can reveal global extent of forced labor in the world's fishing fleet

Gavin G. McDonald[a,b,1], Christopher Costello[a,b], Jennifer Bone[a,b], Reniel B. Cabral[a,b], Valerie Farabee[c], Timothy Hochberg[d], David Kroodsma[d], Tracey Mangin[a,b], Kyle C. Meng[a,e], and Oliver Zahn[f]

[a]Bren School of Environmental Science & Management, University of California, Santa Barbara, CA 93106; [b]Marine Science Institute, University of California, Santa Barbara, CA 93106; [c]Liberty Shared, Washington, DC 20001; [d]Global Fishing Watch Inc., Washington, DC 20036; [e]Department of Economics, University of California, Santa Barbara, CA 93106; and [f]Google, Mountain View, CA 94043

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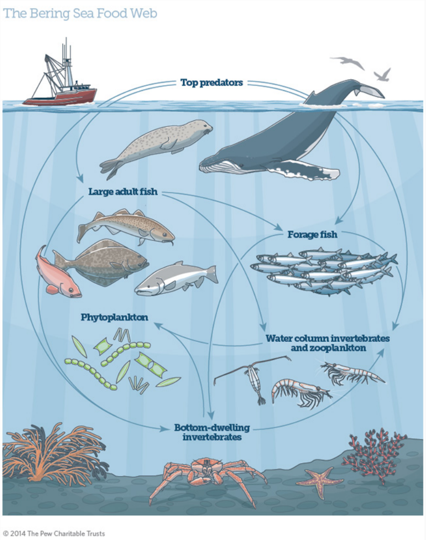
While forced labor in the world's fishing fleet has been widely documented, its extent remains unknown. No methods previously existed for remotely identifying individual fishing vessels potentially engaged in these abuses on a global scale. By combining expertise from human rights practitioners and satellite vessel

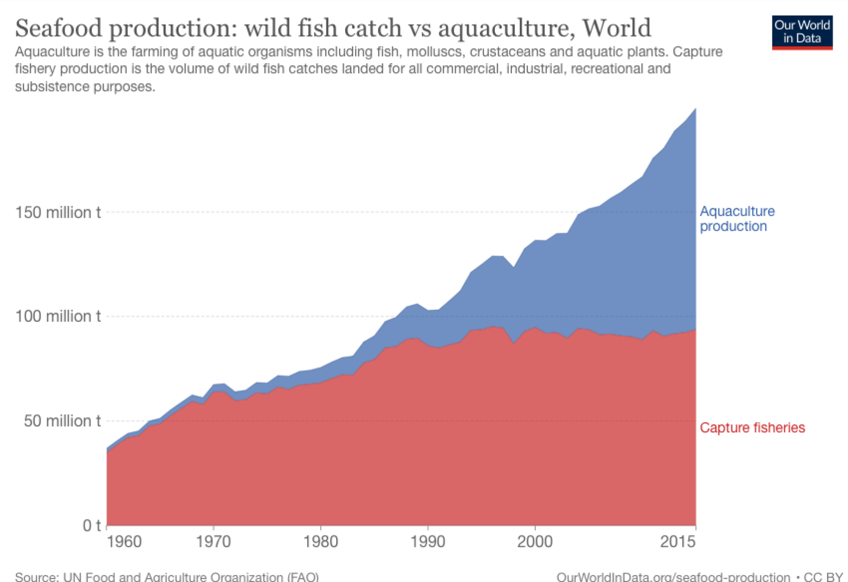
forestry, or fisheries (7). The Global Slavery Index reports that the seven countries with highest slavery risk in 2018 generated 39% of global fisheries catch (3, 8), and Tickler et al. found that the United States has slavery risks of 0.2 kg per metric ton for domestic seafood and 3.1 kg per metric ton for imported seafood

Fisheries: what's the big deal?



Source: PewTrusts

Fisheries: what's the big deal?

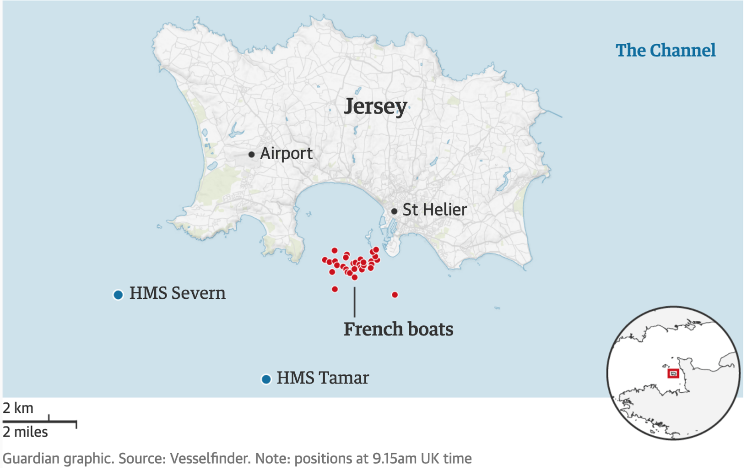


Fisheries: what's the big deal?

Source: Punch, January 17th, 1891

Fisheries: what's the big deal?

About 80 French boats gathered at the port in St Helier to protest against post-Brexit rules on fishing rights



Source: *The Guardian*, 05/05/2021.

Fisheries: what's the big deal?

INTER-AMERICAN TROPICAL TUNA COMMISSION
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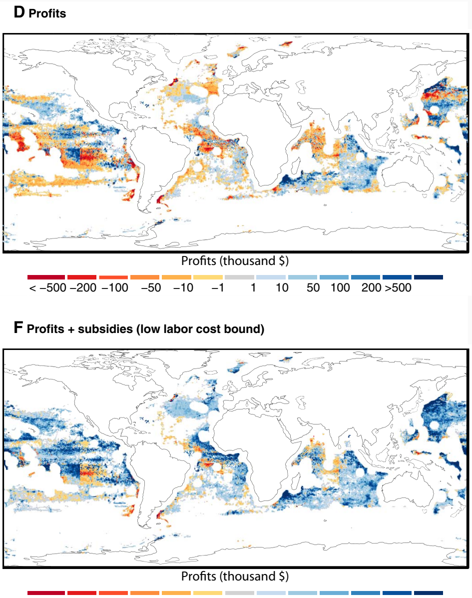
Bulletin — Boletin
Vol. I, No. 2

SOME ASPECTS OF THE DYNAMICS OF POPULATIONS
IMPORTANT TO THE MANAGEMENT OF THE
COMMERCIAL MARINE FISHERIES

by
MILNER B. SCHAEFER

Fisheries: what's the big deal?

Source: Sala et al. (2018)



Fisheries: what's the big deal?

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WTO must complete an ambitious fisheries subsidies agreement

U. Rashid Sumaila[1,2]✉, Lubna Alam[1], Patrizia R. Abdallah[3], Denis Aheto[4], Shehu L. Akintola[5], Justin Alger[6], Vania Andreoli[7,8], Megan Bailey[9], Colin Barnes[10], Abdulrahman Ben-Hasan[11], Cassandra M. Brooks[12,13], Adriana R. Carvalho[14], William W. L. Cheung[1], Andrés M. Cisneros-Montemayor[15], Jessica Dempsey[16], Sharina A. Halim[17], Nathalie Hilmi[18], Matthew O. Ilori[19], Jennifer Jacquet[20], Selma T. Karuaihe[21], Philippe Le Billon[2,16], James Leape[22], Tara G. Martin[23], Jessica J. Meeuwig[8], Fiorenza Micheli[24], Mazlin Mokhtar[17,25], Rosamond L. Naylor[26], David Obura[27], Maria L. D. Palomares[28], Laura M. Pereira[29,30], Abbie A. Rogers[31], Ana M. M. Sequeira[32,33], Temitope O. Sogbanmu[34], Sebastian Villasante[35], Dirk Zeller[7] and Daniel Pauly[1,28]

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The World Trade Organization (WTO) achieved a significant milestone in June 2022 by adopting a much-anticipated fisheries subsidies agreement[1], aligning with strong recommendation from the global scientific community[2]. This pivotal sustainable and equitable pathway forward with a commitment to more equitable trade.

We, a coalition of scientists representing all inhabited continents, urge the WTO to conclude the second round of

Fisheries: what's the big deal?

"More than 80% of our ocean is unmapped, unobserved, and unexplored." (NOA)

Compare to 100% 100-m mapping of the Moon, Mars, 98% Venus. (The Conversation)

"... it's expensive, difficult, and uninspiring." (In *Forbes*, online, 2013)

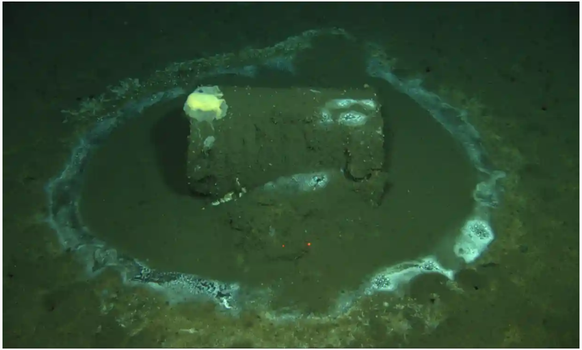
(Note the log scale.)

Fisheries: what's the big deal?

"**Dilution is the solution to pollution**": old doctrine in pollution management.

Oceans have long been a dumping ground for innocuous to extremely harmful waste.

Glass Beach: Fort Bragg, California. (*visitmendocino.com*)



DDT barrel off Southern California coast. (In: *The Guardian*, online, 2023)

But also: fishing nets, farming effluents, pharmaceutical substances, etc.

Oceans/Fisheries: What is so interesting to an economist? Coda

Oceans and the life forms they host can be seen as an asset delivering flows of goods and services (Heal, 2020).

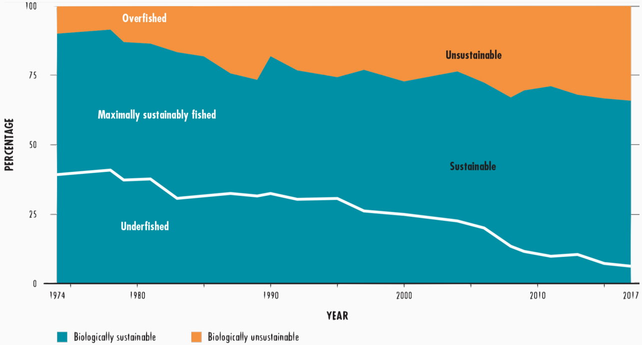
The challenges associated to their management are economic questions, and affect the lives of millions.

Anthropogenic pressures are changing and demand new policy solutions.

Introduction

A policy gap

Despite recent improvements many fisheries remain unsustainably managed.



The State of World Fisheries and Aquaculture (FAO, 2020b).

Some management methods have been shown to work well (Costello et al., 2008), but are not / cannot be applied everywhere (high seas, etc.). Typically focus on limiting catch via quotas, seasons, or gear restrictions. **Blindspot:** “demand-side” interventions.

Demand for demand-side interventions

"Demand-side" interventions are gaining traction among conservationists (e.g., cf. Halpern et al., 2021).

Rely on changes in **demand** to reduce catch, e.g.: information interventions, substitution (aquaculture, lab-grown flesh), taxes.

Are these likely to do better than / complement "supply-side" interventions?

→ Implicit hypothesis: **NEED** fishing effort to be responsive to prices.

- What is the elasticity of supply?
- Can demand-side interventions rebuild global fisheries?

A matter of elasticities

Using global data on fisheries assessment and ex-vessel prices, this paper asks:

Absent management, are demand-side interventions suited to attain sustainability in fisheries?

Method: **leverage the segmented nature of fish supply** to get plausibly exogenous variations in prices and estimate the supply elasticity of seafood; compare policy options.

Preview of the results

1. **Instrumental variable strategy** using the segmented nature of production as a price-shifter works, first-ever supply elasticity for (wild-caught) fish.
2. **Fisheries supply elasticity** is small (0.12), and robust to alternative specifications or strategies.
3. **Demand-side interventions** barely deviate from the BAU scenario, no matter how mild or extreme.
4. **Supply-side interventions** (quota), on the other hand, lead to recovery while not detrimental to prices.

Contributions to economics, fisheries economics, and policy

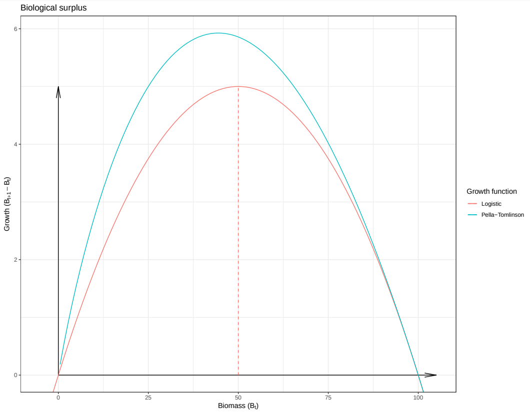
1. **Elasticity of supply:** we uncover a fundamental parameter of an important sector, suggest why so low.
   Griliches (1959); Roberts and Schlenker (2013)
2. **Methodological contribution:** we connect a model of supply and demand to a bioeconomic fisheries model. New instruments (segmented markets).
   ?Weitzman (2002)
3. **Demand- vs. supply-side interventions:** we solve a somewhat confidential theoretical debate, address quantitatively the merits of voguish policy options.
   Weitzman (2002); Jensen and Vestergaard (2003); Hannesson and Kennedy (2005); Hansen (2008); Halpern et al. (2021)

Data

Useful notation

A fish stock is a RR, it grows and gets tapped into:

$$B_{t+1} = B_t + F(B_t) - qB_tE_t$$



$K = 100$, $r = 0.2$, $p = 0.5$.

Most productive when harvested at MSY.
Logistic: $B_{MSY} = K/2$, and MSY$= rK/4$.

MSY conditions are used to rescale fisheries variables:

$b = B/B_{MSY}$

$h = H/MSY$

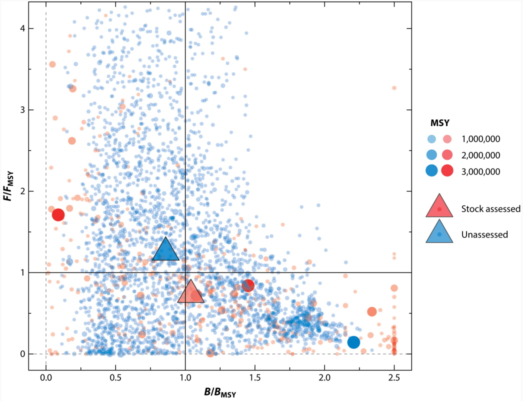
$F = H/B$ and $f = h/b$.

Fisheries assessment and management

Stock assessments are key to fisheries management. The RAM database compiles them; those fisheries ($N_M = 893$) are considered well managed, generally with a quota.

Unassessed fisheries ($N_U = 2,287$) tend to have weaker management. Their status is obtained by combining data sources in the "Upsides" database (Costello et al., 2016).

More on how ▷



Data sources

- **Stock status** for assessed and unassessed fisheries: RAM-LDB, Upsides (1980-2012) (Costello et al., 2016; RAM Legacy Stock Assessment Database) → B/B_{MSY}, H/MSY, F/F_{MSY}
- **Ex-vessel prices** fish species (or group), year level, 1976-2012: Melnychuk et al. (2017) (converted to real 2012 USD/kg). 187 time series.
- **Aquaculture**: FAO's FishStat J (FAO, 2020a).
- **TAC**: Hilborn et al. (2020); Melnychuk et al. (2021).

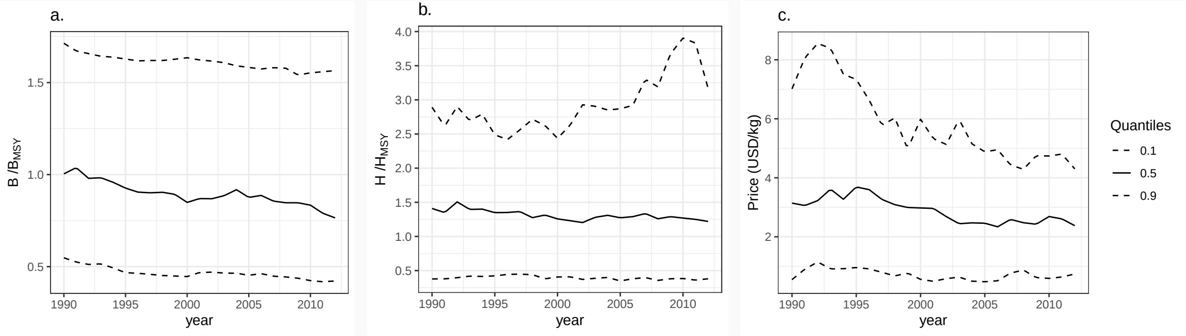
Sample: 2,287 unmanaged stocks across 52,601 stock-years, comprising 464 unique species.

Descriptive statistics

Variable	Mean	Median	Min	Maximum	Std dev.
Ex-vessel price (USD/kg)	3.393	2.581	0.068	27.699	3.883
Unmanaged stocks (N=2,287)					
Relative biomass	0.963	0.839	0.070	2.420	0.456
Relative harvest	1.373	1.320	0.001	8.824	0.831
Fishing pressure	1.716	1.585	0.001	6.318	1.059
Managed stocks (N=893)					
Catch (10^6 tons)	1.793	0.642	0.000	19.198	3.266
TAC-constrained catch (10^6 tons)	0.315	0.014	0.000	9.061	1.150

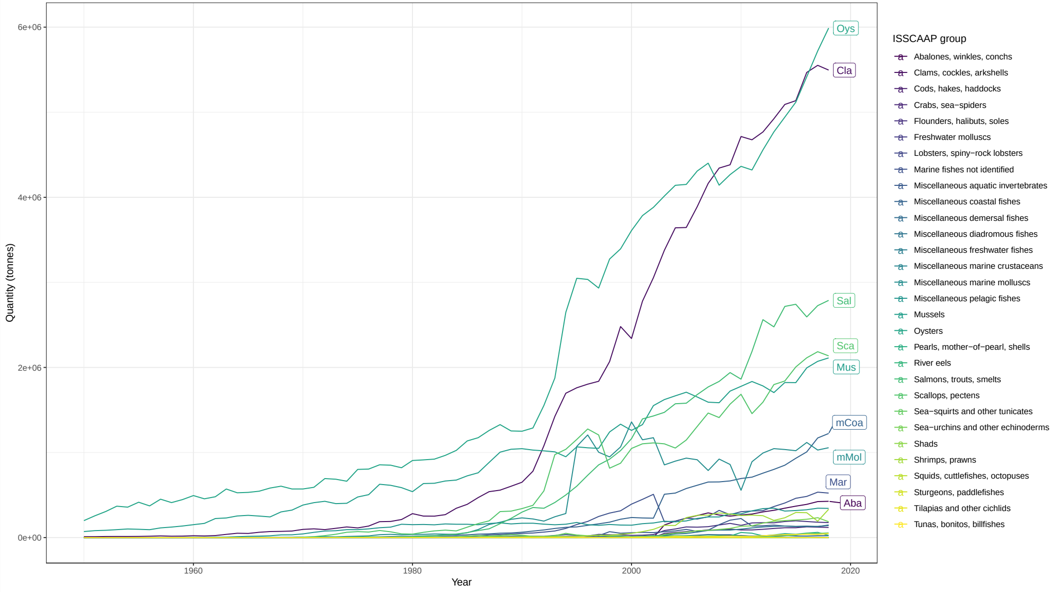
Notes: Summary statistics are at the ISSCAAP group by year level. *Catch* stands for the quantity (in 10^6 tons) of fish caught within a year and an ISSCAAP group in stocks represented in the RAM database. *TAC-constrained catch* (in 10^6 tons) is the subset of *Catch* stocks such that the catch-to-TAC (total allowable catch) ratio is between 0.9 and 1.1. Relative biomass and harvest are dimensionless (and relative to the biomass and harvest, respectively, ensuring maximum sustainable yield); fishing pressure is dimensionless as well, as the ratio of harvest over biomass.

Trends in unmanaged fisheries



Empirical strategy

IV: Intuition – Aquaculture in seafood production



IV: Conceptual framework

Annual supply and demand of seafood follows:

$$q_t^D = \alpha_0 - \alpha_1 p_t + \varepsilon_t^D \quad (1)$$
$$q_t^W = \beta_0 + \beta_1 p_t + \varepsilon_t^W \quad (2)$$
$$q_t^F = \bar{S}_t + \varepsilon_t^F \quad (3)$$

And: $q_t^D = q_t^W + q_t^F, \forall t$

→ Supply is segmented.

→ Supply coming from farmed sources (q_F) can serve as price shifter to the wild supply (q_W).

Bias of the OLS coefficient ▷

IV: Aquaculture production as a price shifter

Prices and quantities of wild-caught fish are endogenous.

Idea: Aquaculture products are close substitutes (relevance) but quantities are determined by aquaculture-specific dynamics and constraints (exogeneity).

First stage:

$$p_{st} = \alpha_1 aqua_{st} + \theta_1 b_{st} + \theta_2 b_{st}^2 + \delta_t + \nu_{st}$$

Estimate the effect of price on (relative) catch/mortality:

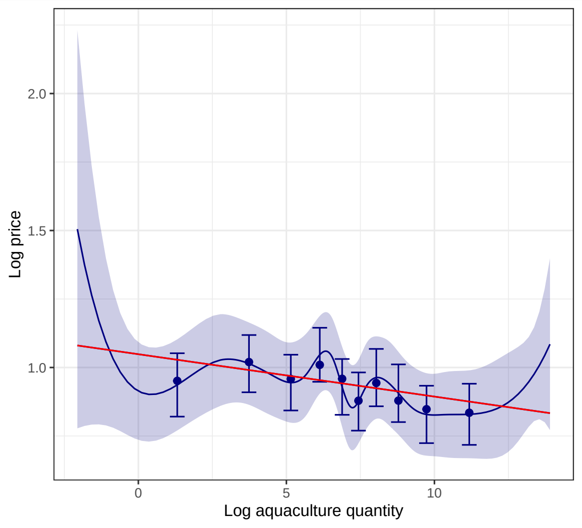
$$y_{st} = \beta_1 \widehat{p_s t} + \gamma_1 b_{st} + \gamma_2 b_{st}^2 + \lambda_t + \varepsilon_{st} \tag{4}$$

With:

- y_{st}: relative catch ($h = H/MSY$) or mortality ($f = F/F_{MSY}$) for stock s in year t
- b_{st}: relative biomass (B/B_{MSY}) of stock s in year t
- p_{st}: ex-vessel price

Results

Results: Aquaculture IV – Graph



Binscatter using optimal bins (Cattaneo et al., 2024), controlling for year fixed effects and a quadratic in normalized biomass.

Results: Aquaculture IV

More ▷

	OLS	FS	TSLS
	(1)	(2)	(3)
Ln price	0.078^{***}		0.575^{***}
	(0.009)		(0.056)
B/B_{MSY}	-0.873^{***}	0.006	-1.048^{***}
	(0.019)	(0.013)	(0.019)
${B/B_{MSY}}^2$	0.034^{***}	$0.002^{\cdot}$	0.043^{***}
	(0.001)	(0.001)	(0.002)
Ln quantity (aquaculture)		-0.045^{***}	
		(0.002)	
Num. obs.	21,542	21,542	21,542
R^2 (proj model)	0.142	0.024	0.099
F-stat 1st stage		180.045	104.753

Notes: $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $\cdot < 0.1$. Sample: all. Independent variable: price (instrumented with: ln aquaculture). Dependent variable: ln effort or mortality (fvfmsy). Year FEs in (1), (2), (3).

Table 1: Prices on effort and catch, instrumenting with aquaculture

Simulations

Scenarios. For unmanaged stocks, from 1990 onward (2012):

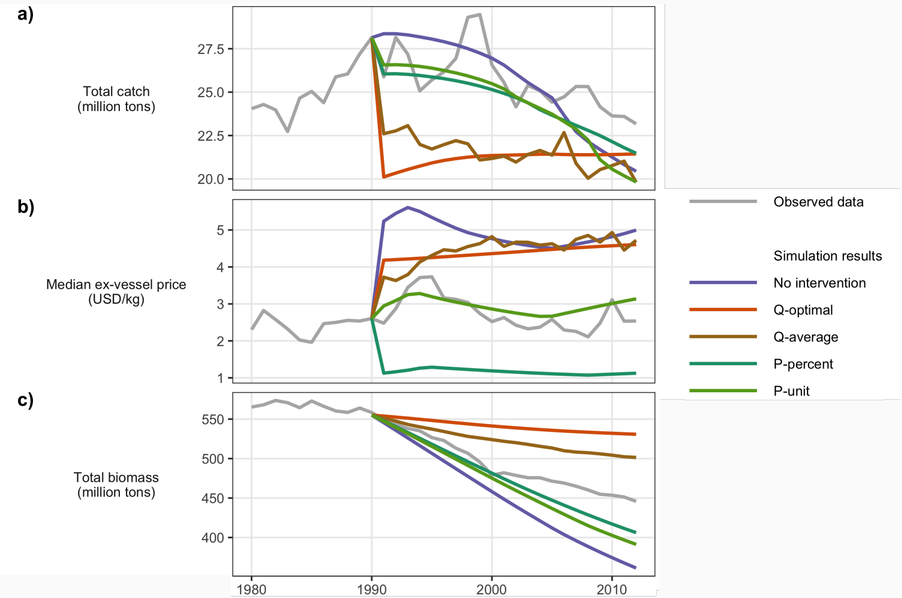
- BAU: stocks remain unmanaged, fished according to equilibrium prices;
- "P scenarios": simulate demand shift / tax, price-responsive but lower demand;
- "Q scenarios": simulate management (ideal, realistic), supply at quota or less.

Procedure. Building on the conceptual framework (IV2), for all t:

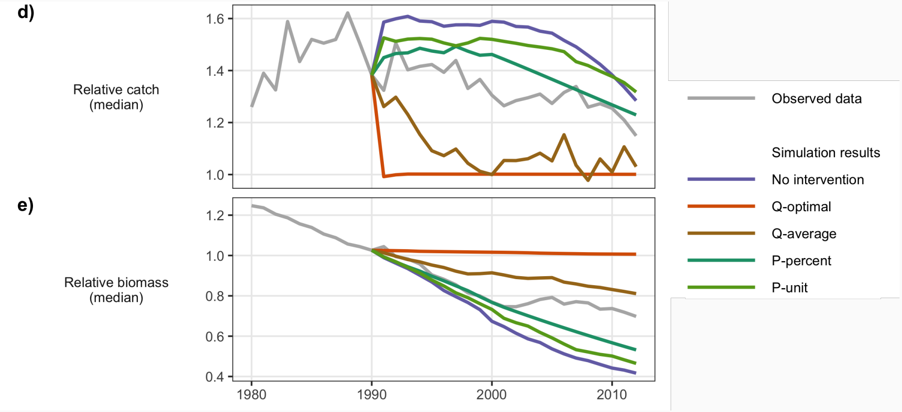
1. Draw demand curves from the data (Costello et al., 2020);
2. Intersect the supply curve (BAU + P);
3. ... or intersect the quota (Q);
4. Get equilibrium price and quantity caught;
5. Transmission to $t+1$ with Pella-Tomlinson model (Pella and Tomlinson, 1969).

Equation ▷

Results: Simulations



Results: Simulations

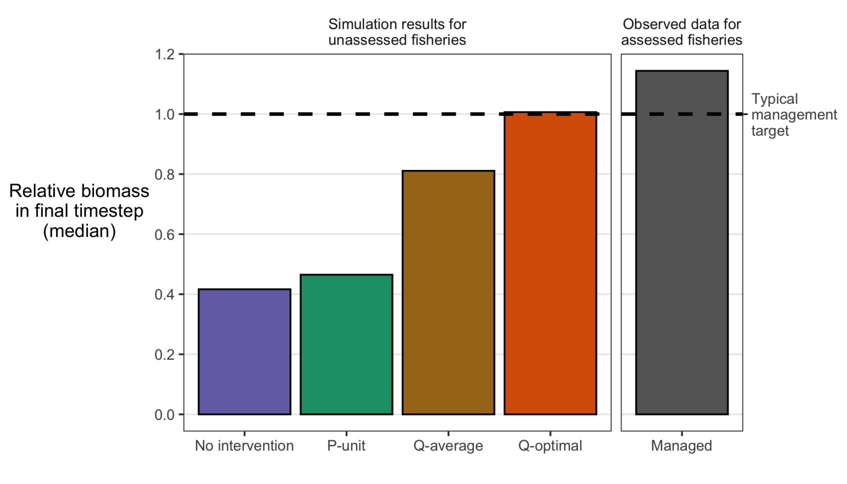


Results: redux

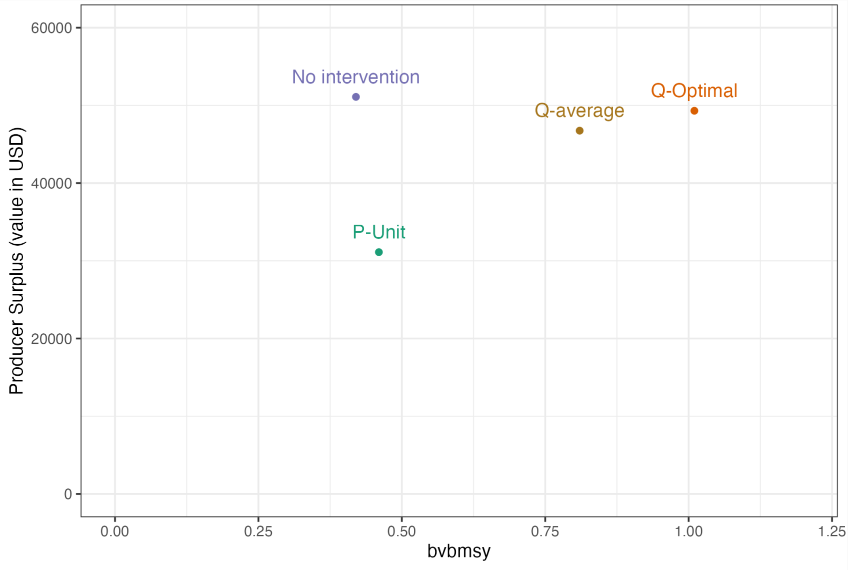
	No intervention	Q-optimal	Q-average	P-percent	P-unit
Median ex-vessel price (USD/kg)	5.00	4.60	4.72	1.12	3.14
Total biomass (million tons)	361.29	530.80	501.47	406.15	391.27
Total catch (million tons)	20.44	21.44	19.81	21.48	19.82
Relative fishing pressure (median)	2.76	1.00	1.30	2.11	2.28
Relative biomass (median)	0.42	1.01	0.81	0.53	0.46
Relative catch (median)	1.28	1.00	1.03	1.23	1.32
Collapsed stocks	2.00	1.00	1.00	1.00	2.00
Median post-tax price (USD/kg)	5.00	4.60	4.72	6.90	6.14
Change in total biomass (%)	-34.91	-4.37	-9.66	-26.83	-29.51
Change in total catch (%)	-27.35	-23.80	-29.59	-23.67	-29.55

Summary statistics from simulations. Percent change statistics represent changes in values from 1990 to 2012; all other statistics represent the value in 2012 (final time step).

Results: final biomass & producer surplus



Results: final biomass & producer surplus



Robustness & sensitivity

Verify innocuity of assumptions:

- Regression specification; See ▷
- Is there such a thing as *one* price? *one* elasticity? One price ▷ ElasticitieS ▷
- Long(ish)-term elasticity (in progress);
- Non-zero correlation between error terms; See ▷
- Policy aggressiveness. See ▷

Conclusions

Parting thoughts

Using global data on fisheries in IVs we have calculated the supply elasticity of fisheries.

It is low; in simulations that account for the biology of fish stocks, that leads to mediocre performance of the demand-side policies.

Further work to determine:

- why the elasticity is so low (we think: subsidies, possibly capital);
- why we get different elasticities in IV 1 & 2 (we think: different samples);
- whether demand-side interventions might still work for some species / ISSCAAP groups;
- a more realistic counterfactual quota scenario (Q-average too demanding?);
- long-term elasticity of supply.

Further thoughts:

- external validity? (unclear)
- substitution between species/stocks?

Thank you!

Questions?

Contact me: anouch.missirian@tse-fr.eu

Or my coauthors: Olivier Deschênes, Christopher Costello, Gavin McDonald, Mike Melnychuk.

Appendix

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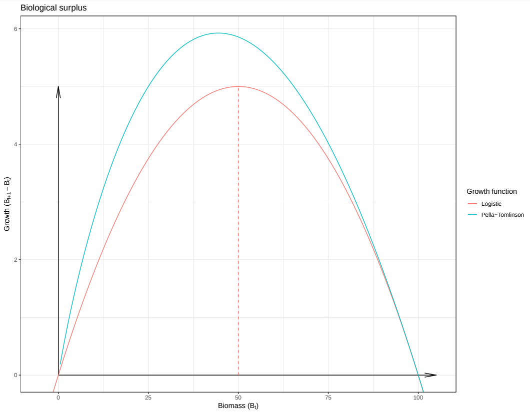
What do we talk about when we talk about sustainable fisheries management?

Fisheries 101: A fish stock is a RR, it grows and gets tapped into:

$$B_{t+1} = B_t + F(B_t) - qB_tE_t$$



$K = 100$, $r = 0.2$, $p = 0.5$.

Most productive when harvested at MSY.

Logistic: $B_{MSY} = K/2$, and MSY$= rK/4$.

MSY conditions are used to rescale fisheries variables:

$b = B/B_{MSY}$

$h = H/MSY$

$F = H/B$ and $f = h/b$.

The Upsides database (Costello et al., 2016)

The Upsides database provides status assessment for unassessed fisheries by combining:

- FAO landings data (FAO Global Marine Capture Production Database: annual, somewhat geographically resolved)
- SOFIA Assessment Database
- FishBase life history traits (species, or species group level)

... through a structural fisheries modeling and regression two-step approach.

$\Rightarrow$ stock assessment for 5,338 fisheries not found in RAM.

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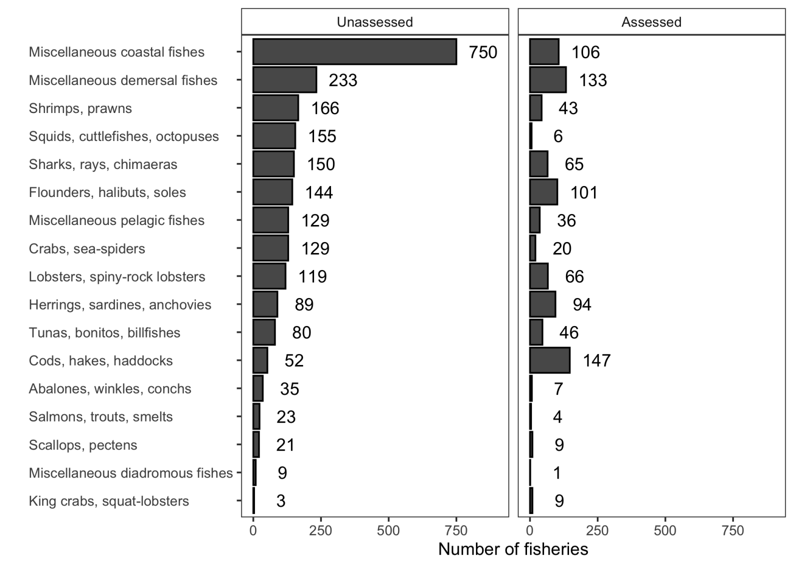
IV 2: Intuition – The Bristol Bay Salmon Run (AK)

IV 2: Intuition – Beyond Anecdotal



IV 2: Conceptual framework

Annual supply and demand of seafood follows:

$$q_t^D = \alpha_0 - \alpha_1 p_t + \varepsilon_t^D \quad (1)$$
$$q_t^U = \beta_0 + \beta_1 p_t + \varepsilon_t^U \quad (2)$$
$$q_t^M = \bar{S}_t + \varepsilon_t^M \quad (3)$$

→ Supply coming from managed fisheries (q_M) can serve as price shifter.

Bias of the OLS coefficient ▷

IV 2: TAC

Idea: leverage variation in annual quota set by *regulated* fisheries.

First stage (s species, g ISSCAAP group, t year):

First stage ▷

$$p_{sgt} = \pi_0 + \pi_1 q^M_{gt} + \theta_1 b_{sgt} + \theta_2 b^2_{sgt} + \lambda_t + u_{sgt} \quad (4)$$

Second stage:

$$h_{sgt} = \beta_1 \hat{p}_{sgt} + \gamma_1 b_{sgt} + \gamma_2 b^2_{sgt} + \delta_t + \varepsilon_{sgt} \quad (5)$$

(Standard errors are two-way clustered at the species-year and country levels.)

Hinges on the fact that **quotas in managed fisheries** are **exogenously determined** (as far as the unregulated supply is concerned, as good as random), affect unregulated supply only through their effect on prices at the ISSCAAP group and year level.

Results: TAC IV

More first stage ▷

Dep. var.: h_{it}	OLS	First-stage	TSLS
Model →	(1)	(2)	(3)
Ex-vessel price (USD/kg)	0.01***	––	0.05***
	(0.00)		(0.01)
B/B_{MSY}	3.12***	0.16	3.25***
	(0.15)	(1.34)	(0.17)
${B/B_{MSY}}^2$	-1.42***	-0.47	-1.43***
	(0.07)	(0.52)	(0.08)
RAM catch with binding TAC	––	-0.62***	––
		(0.04)	
Implied elasticity	0.03	–	0.12
1st stage F-stat.	–	1,447.8	1,447.8
Observations	52,601	45,852	45,852

*Signif. codes: ***: 0.001, **: 0.01, *: 0.05.* B/B_{MSY} is the relative biomass.

Table 2: Prices on effort and catch, instrumenting with TAC-regulated stocks

Definition of the instrument

Back to results ▷

Dependent Variable:	hvhmsy			
	IV: RAM catch		IV: Catch TAC caught	
Model:	(1)	(2)	(3)	(4)
Variables				
(Intercept)	-0.145.		-0.255**	
	(0.081)		(0.097)	
price_usd_kg_real	0.033***	0.035***	0.046***	0.048***
	(0.009)	(0.008)	(0.012)	(0.013)
bvbmsy	3.13***	3.12***	3.25***	3.24***
	(0.163)	(0.165)	(0.170)	(0.171)
bvbmsy square	-1.42***	-1.41***	-1.43***	-1.43***
	(0.078)	(0.077)	(0.076)	(0.075)
Fixed-effects				
factor(year)		Yes		Yes
Fit statistics				
F-test (1st stage)	3,416.0	3,739.2	1,447.8	1,366.9

Two-way (commonname,year) & iso3) standard-errors in parentheses
*Signif. Codes: ***: 0.001, **: 0.01, *: 0.05, .: 0.1*

Aquaculture IV: first stage

Back ▷

	(1)	(2)
Quantity (kg)	$-5.877e^{-07**}$	
	$(2.035e^{-07})$	
Ln quantity		-0.017^{***}
		(0.004)
F-stat	8.343	17.940
Clustering	none	none
Num. obs.	21542	21542
R^2 (full model)	0.437	0.438
R^2 (proj model)	0.000	0.001
Num. groups: obscell	238	238
Num. groups: year	33	33

Notes: $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. Table shows OLS regression of aquaculture quantities (aggregated at the ISSCAAP group x country x year level) on wild catch prices, with year and ISSCAAP x country fixed effects. The independent variable is either the quantity (column 1) or the logged quantity (column 2). The dependent variable is the logged price (in USD/kg). Robust s.e.

Table 3: First stage: predicting prices with aquaculture quantities

Aquaculture IV: second stages

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Table 4: IV: instrumented prices on effort and catch

	(1)	(2)	(3)	(4)
$\widehat{\text{Ln price}}$	0.667^{***}	0.575^{***}	0.750^{***}	0.617^{***}
	(0.076)	(0.056)	(0.080)	(0.059)
$^{B}/_{B_{MSY}}$	-1.050^{***}	-1.048^{***}	0.118^{***}	0.121^{***}
	(0.020)	(0.019)	(0.021)	(0.020)
$^{B}/_{B_{MSY}}{}^{2}$	0.043^{***}	0.043^{***}	-0.010^{***}	-0.009^{***}
	(0.002)	(0.002)	(0.002)	(0.002)
Dep. var.	LnEffort	LnEffort	LnCatch	LnCatch
Instrument	Quantity	LnQuantity	Quantity	LnQuantity
F-stat 1st stage	77.577	104.753	87.252	109.681
Std. err.	robust	robust	robust	robust
Num. obs.	21,542	21,542	21,542	21,542
R^2 (proj model)	0.049	0.099	−0.188	−0.100

Notes: $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. Table shows IV regression of seafood prices (logged, USD/kg) instrumented by aquaculture quantities (at the ISSCAAP level), on fishing effort (logged, columns 1-2) and catch (logged (kg), columns 3-4), with year

Bias of the OLS coefficient

Recall:

$$
\begin{aligned}
q_t^D &= \alpha_0 - \alpha_1 p_t + \varepsilon_t^D && (6)\\
q_t^U &= \beta_0 + \beta_1 p_t + \varepsilon_t^U && (7)\\
q_t^M &= \bar{S}_t + \varepsilon_t^M && (8)
\end{aligned}
$$

Suppose: $\varepsilon_t^U = \rho\varepsilon_t^M + (1-\rho)\,\tilde{\varepsilon}_t^U$, where $\tilde{\varepsilon}_t^U$, ε_t^M, ε_t^D uncorrelated, and $\rho \in]0,1[$.

Market clearing yields: $p_t^* = \frac{\alpha_0+\varepsilon_t^D-\beta_0-\bar{S}-(1+\rho)\varepsilon_t^M-(1-\rho)\tilde{\varepsilon}_t^U}{\alpha_1+\beta_1}$

And finally $\frac{dq^U}{dp} = \beta_1 - (\alpha_1+\beta_1)\,\frac{\rho}{1+\rho}$, so unless $\rho = 0$ the OLS estimator of β_1 will be biased.

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Aquaculture instrument: details

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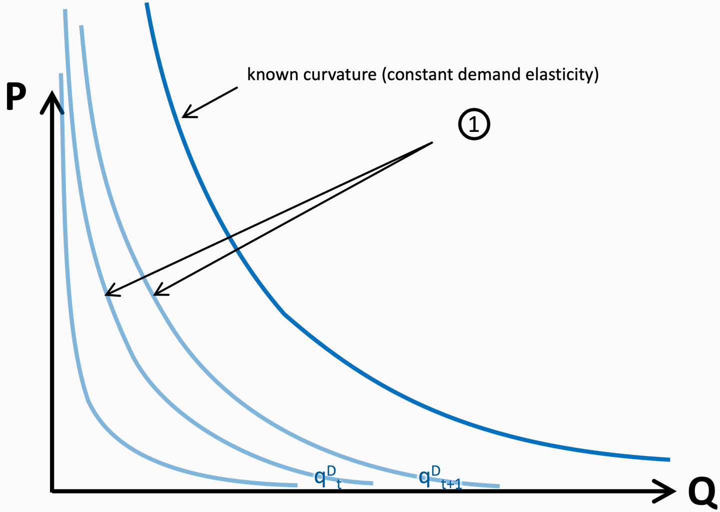
Idea: Supply of farmed fish affects seafood prices (Bjørndal and Guillen, 2016), but drivers of supply are different (in the short run – e.g., licensing, rules and local regulations, grow-out times).

Data: FAO database on aquaculture production.

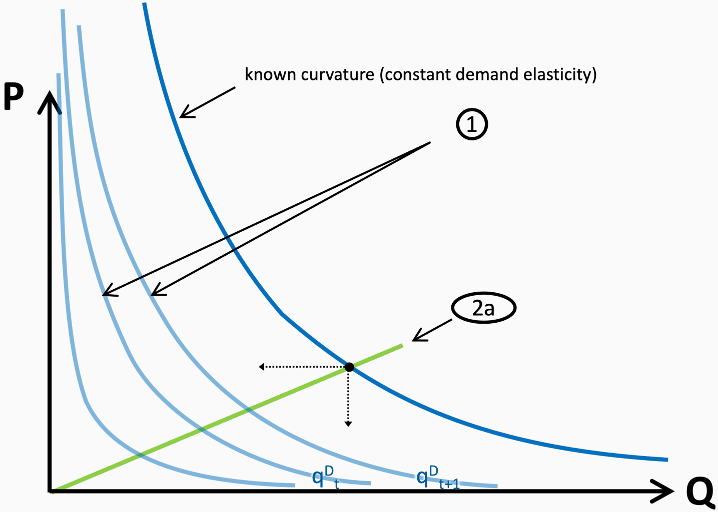
Procedure: 1 – draw demand curves from the data (Costello et al., 2020)

∀i:

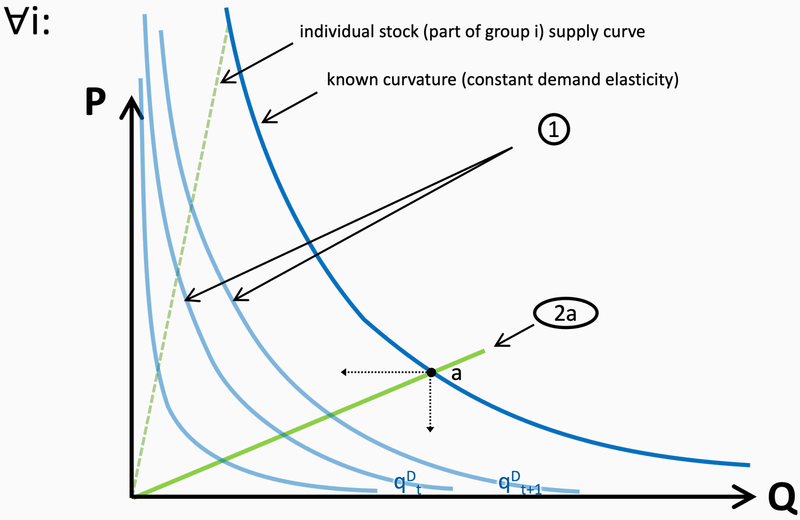


Procedure: 2 – intersect the supply curve (BAU + P)

∀i:

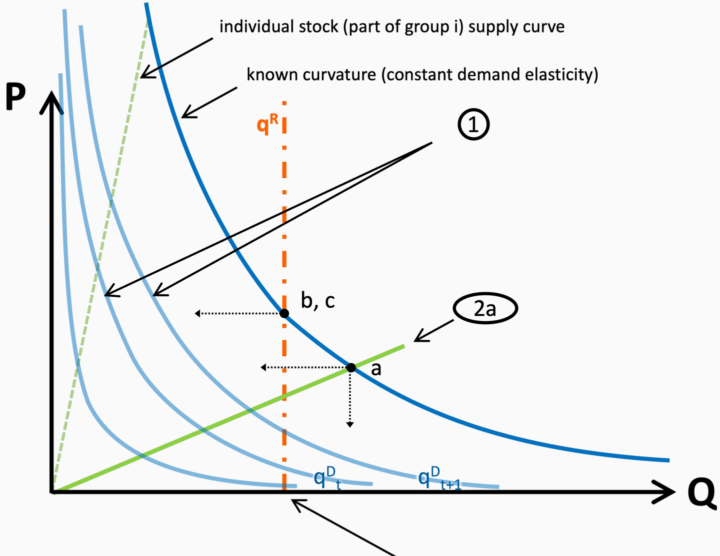


Procedure: 2 – intersect the supply curve (BAU + P)



Procedure: 3 – or intersect the quota (Q)

∀i:



Procedure: 4 – transmission to $t+1$ with Pella-Tomlinson model

Relative biomass follows:

$$b_{it+1} = b_{it} + \frac{\phi+1}{\phi} \times g \times b_{it}(1 - \frac{{b_{it}}^{\phi}}{\phi+1}) - g \times h_{it}$$

Regressions

Dependent Variable:	ln_hvhmsy			
	IV: RAM catch		IV: Catch TAC caught	
Model:	(1)	(2)	(3)	(4)
Variables				
(Intercept)	-1.29***		-1.36***	
	(0.084)		(0.092)	
ln_price	0.077***	0.083***	0.123***	0.121**
	(0.022)	(0.021)	(0.036)	(0.038)
bvbmsy	3.12***	3.11***	3.18***	3.18***
	(0.124)	(0.126)	(0.119)	(0.119)
$bvbmsy^2$	-1.45***	-1.45***	-1.45***	-1.46***
	(0.052)	(0.051)	(0.051)	(0.050)
Fixed-effects				
factor(year)		Yes		Yes
Fit statistics				
F-test (1st stage)	13,158.2	14,223.6	7,441.4	7,474.9

Notes: Signif. codes: ***: 0.001, **: 0.01, *: 0.05, .: 0.1

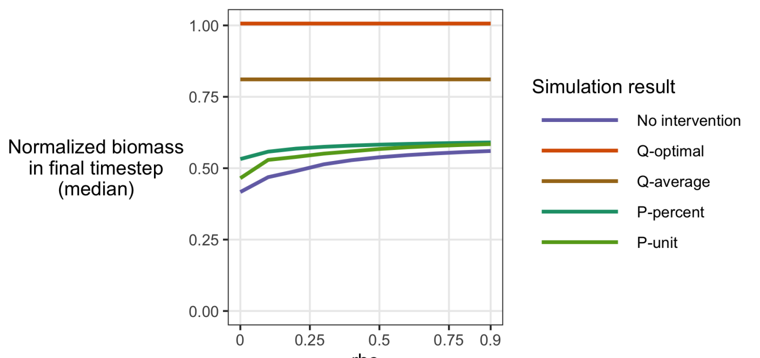
Two-way commonnameXyear & iso3 clustered standard-errors in parentheses.

Back ▷

Sensitivity: Possibility of a non-zero correlation between $\tilde{\varepsilon}^U$ and ε^M

Back ▷

	No intervention	Q-optimal	Q-average	P-percent	P-unit
Median ex-vessel price (USD/kg)	2.26	4.60	4.72	0.78	1.10
Total biomass (million tons)	399.32	530.80	501.47	417.70	419.40
Total catch (million tons)	22.25	21.44	19.81	21.88	21.82
Relative fishing pressure (median)	2.19	1.00	1.30	2.06	2.04
Median post-tax price (USD/kg)	2.26	4.60	4.72	4.81	4.10
Change in total biomass (%)	-28.06	-4.37	-9.66	-24.75	-24.44
Change in total catch (%)	-20.92	-23.80	-29.59	-22.24	-22.47



Varying the value of ρ

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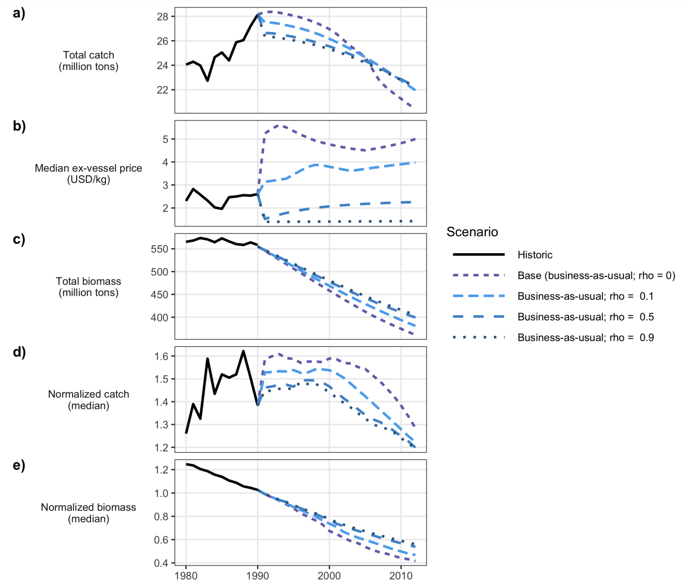

Were we just too harsh?

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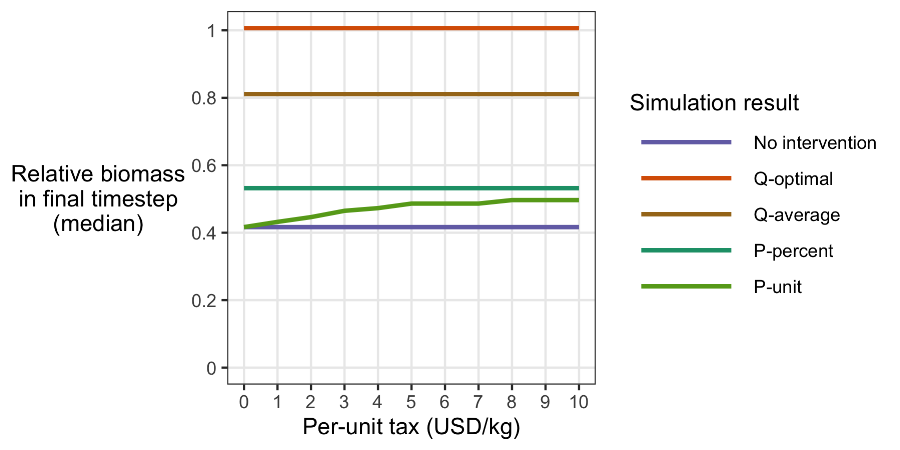
Was a unit tax of 3$/kg just too high?



Is it reasonable to assume there's one price for herring?

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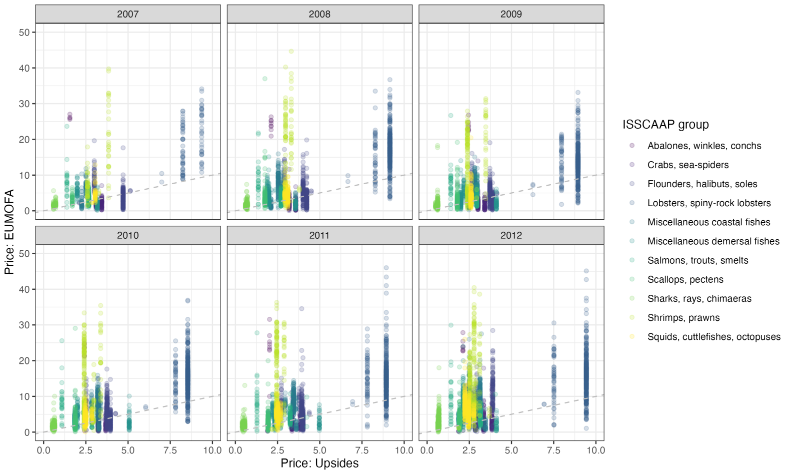
Mostly yes, though some species exhibit substantial variation (across ports):



Prices from Melnychuk et al. (2017) on the horizontal axis, prices from EUMOFA monthly price data

Is it reasonable to assume there's one supply elasticity?

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Of course not. ISSCAAP-group level elasticities make more sense, but the aquaculture instrument isn't able to recover them all: