Multiple Margins of Fishing Behavior: Implications for Predicting the Effects of a Policy Change

Matthew Reimer
University of Alaska Anchorage
Institute of Social and Economic Research

UAA College of Business and Public Policy
UNIVERSITY of ALASKA ANCHORAGE

UAA Institute of Social and Economic Research
UNIVERSITY of ALASKA ANCHORAGE

Multiple Margins of Fishing Behavior

- Fisheries management history: reactive policymaking
  - fishermen have far more flexibility than originally thought
  - new policies react to unanticipated consequences of previous policies

- Example: BC Salmon Limited Entry Program 1969
  - Rapid erosion of effort controls as fishermen expanded into “free” effort dimensions.

- Initial limits on number of vessels
  - ➡ Limit on tonnage of vessels
    - ➡ Limit on length of vessel
      - ➡ Limit on gear types
        - ➡ Limit on combining licenses

Ignoring behavioral margins = regulatory surprises

- Traditional models of the fishing production process ignore the primary behavioral margins of fishermen

  - Early models: aggregate production functions relating industry catch to industry fishing effort

  - Powerful insights: e.g. open access = biological overexploitation + dissipation of rents (Gordon, 1954)

  - Interpretation: "too many boats chasing too few fish." Fix incentives along this margin, and fisheries problem solved!

  - Accumulation of experience shows that other margins are likely to matter.

"The New Fisheries Economics: Incentives Across Many Margins"

M.D. Smith (2012)

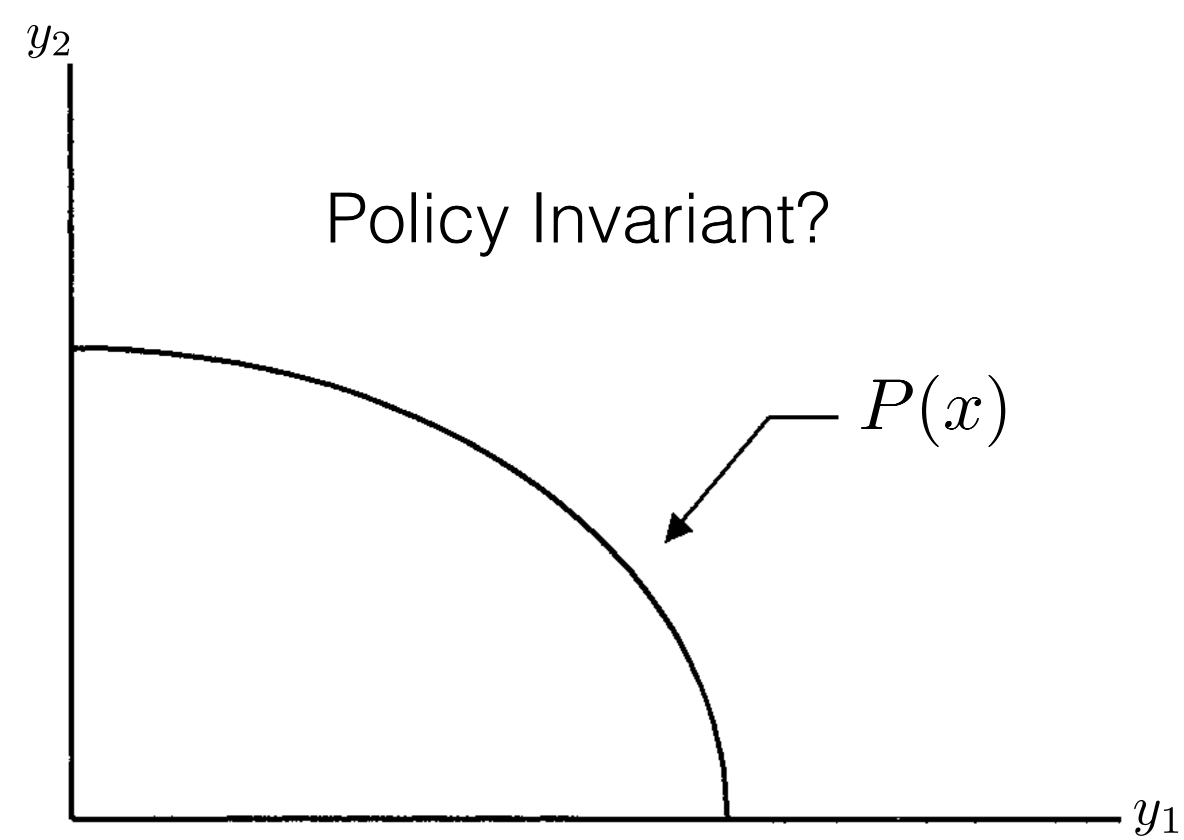
- Multiple margins (extensive and intensive) across which fishermen act
  - amount of gear
  - type of gear
  - number of trips
  - trip length
  - target species
  - fishing grounds
  - product types
  - fish size
  - entry or exit
  - different fisheries

- To what extent should managers control these margins?
  - How can managers control these margins?
  - What are the consequences of ignoring them?
  - How do we know *ex ante* what margins are important?

Fishery Production Models and Policy Invariance

- Conventional aggregate fishery production models that ignore primary behavioral margins do not identify policy invariant parameters

- Catchability parameters and selectivity curves convey biological, technical, and *behavioral* relationships



The Importance of Policy Invariance: Lucas Critique (1976)

- It is naïve to try to predict the outcome of a policy intervention entirely on the basis of a relationship that systematically alters with a change in policy.

- "*Policy invariance facilitates the job of forecasting the impacts of interventions. If some parameters are invariant to policy changes, they can be safely transported to different policy environments*." (Heckman, 2010)

What are the implications of ignoring key behavioral margins when predicting the effects of a policy?

Outline

- Traditional approaches to modeling fishery production
  - How have these been used to predict policy interventions?
- Simulation exercise
  - How does a policy intervention change production relationships when accounting for behavioral margins?
- Empirical investigation of the Bering Sea groundfish fleet
  - Are empirical aggregate production relationships invariant to a policy change that changed fishermen incentives?
- Current and future directions
  - Implications for policy evaluation: where do we go from here?

A Pressing Question: Are Catch Shares Appropriate for Multispecies Fisheries?

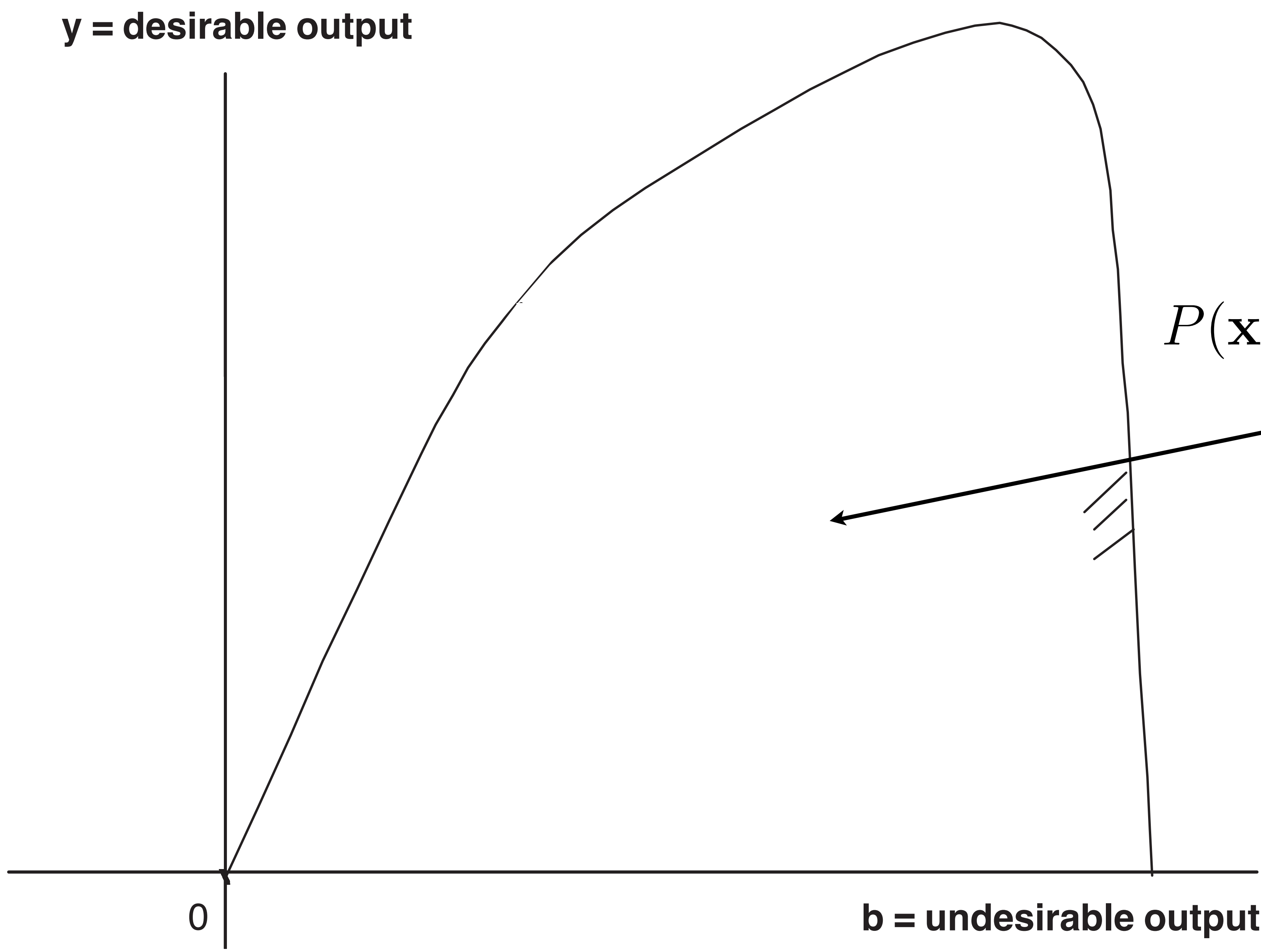
- Catch shares—a secure privilege to harvest a proportion of a fishery's total allowable catch.
  - can be allocated for multiple species
  - can be allocated to individuals, groups, or communities
  - often seen as "the way" to end the "race-for-fish" under open access institutions

A Pressing Question: Are Catch Shares Appropriate for Multispecies Fisheries?

- Can fishermen match their catch composition with a portfolio of quota allocations?
  - fishing gear is not perfectly selective (Squires et al. 1987)
  - could encourage illegal discarding and data fouling (Copes, 1986)
  - “choke” species and unharvested quota
  - selectivity depends on targeting ability (Pascoe et al. 2007)

- Targeting ability—or output substitution capabilities—can be represented via a multi-output production function
  - curvature of the production frontier indicates a fisherman’s “ability” to substitute between species

Output Substitutability with "Bad" Outputs



$$Output\ Set:$$

$$P(\mathbf{x}) = \{(\mathbf{y}, \mathbf{b}) : T(\mathbf{x}, \mathbf{y}, \mathbf{b}) \leq 0\}$$

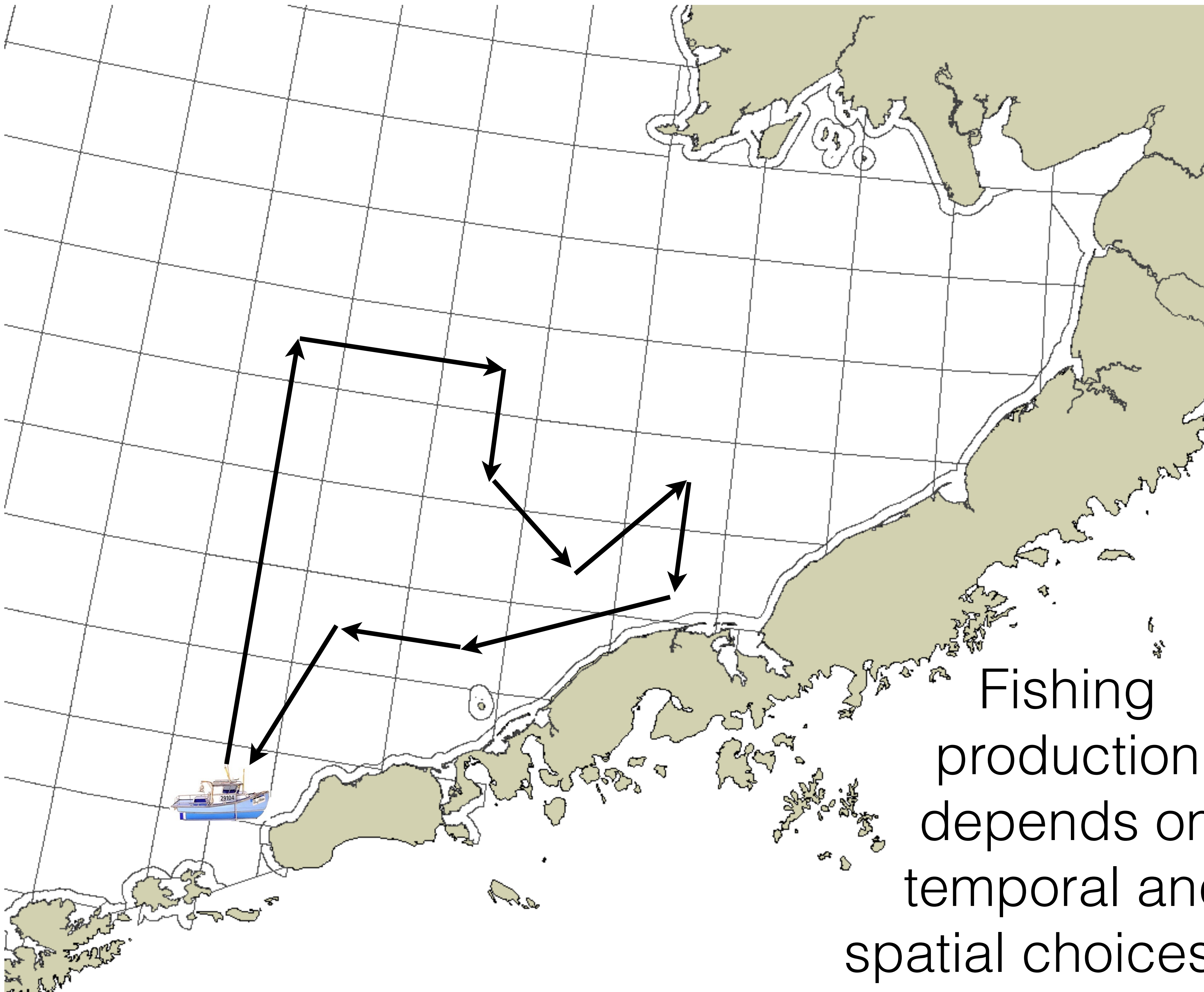
A Pressing Question: Are Catch Shares Appropriate for Multispecies Fisheries?

- Data from non-catch shares fisheries suggest catch shares face serious challenges due to weak substitution possibilities between species
  - e.g. Squires (1987); Squires and Kirkley (1991,1995,1996); Pascoe et al. (2007,2010)

- Evidence from multispecies catch shares shows greater flexibility than previously thought
  - e.g. Branch and Hilborn (2008); Sanchirico et al. (2006)

- Perhaps output substitution revealed through *ex ante* empirical investigations reveal more about behavior and incentives than actual technical relationships.

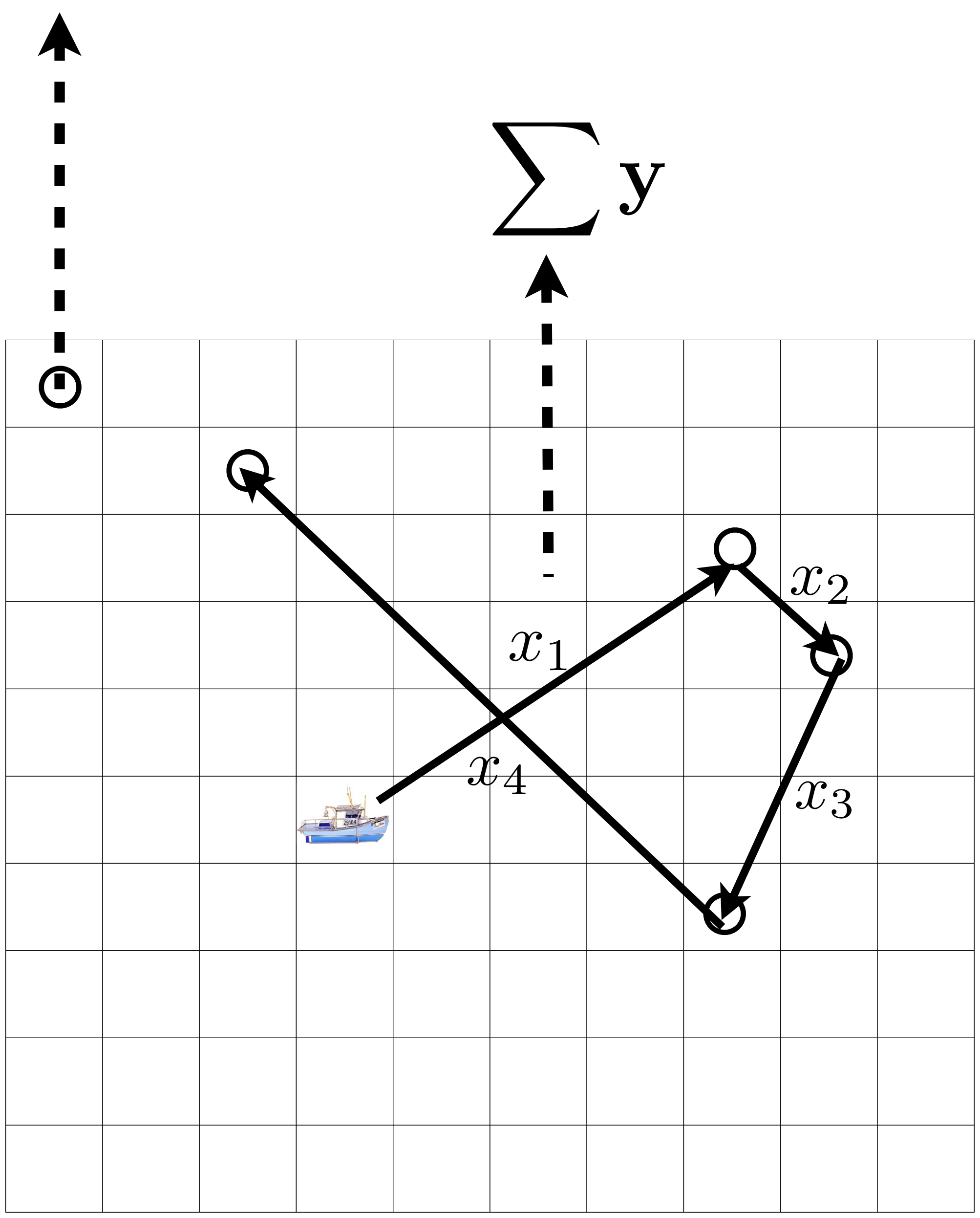
Neglected Margins of Production

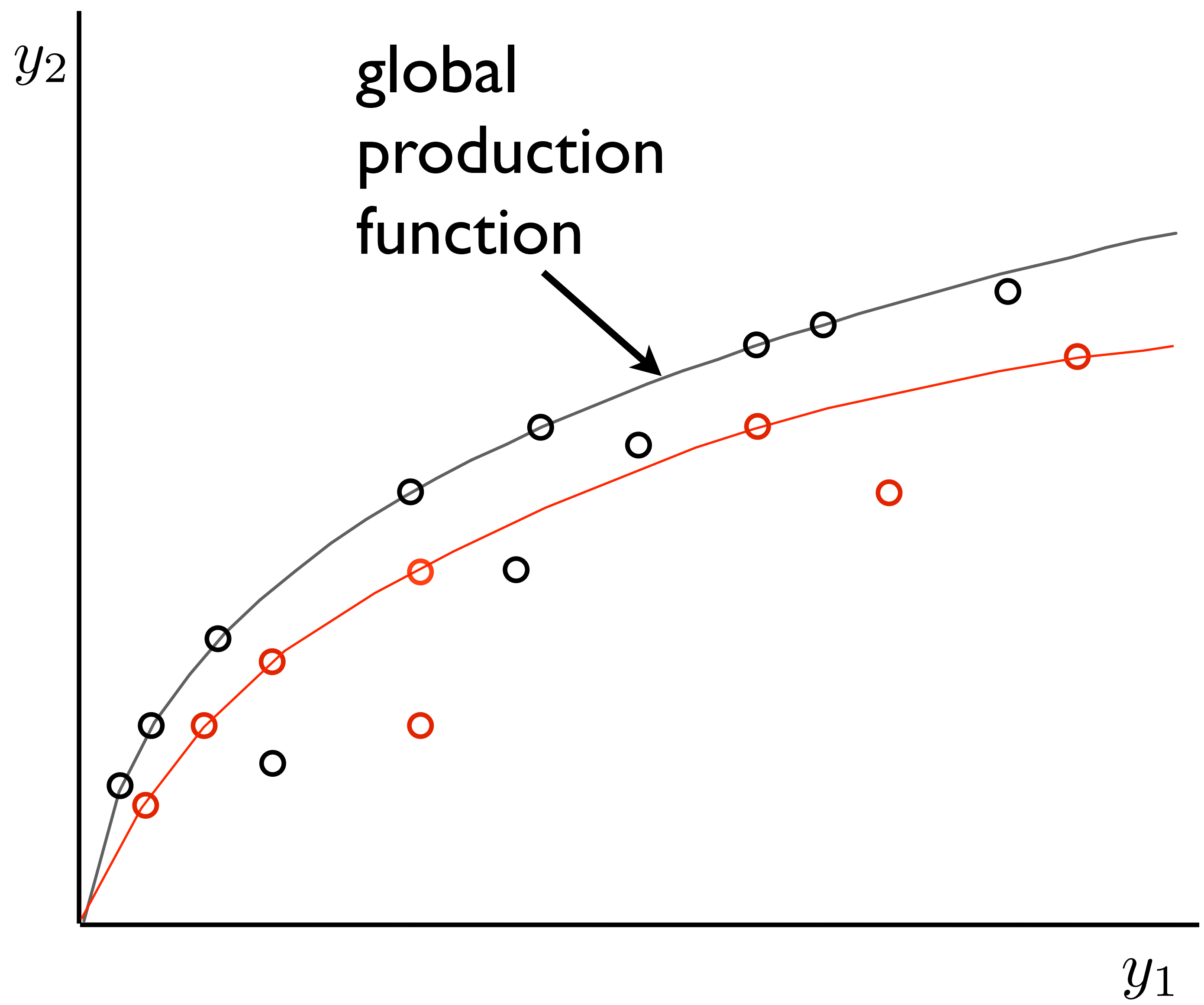


Fishing production depends on temporal and spatial choices.....

Multispecies production function: micro-foundations

local production function: $\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \theta_{1jt} \\ \theta_{2jt} \end{bmatrix} x$

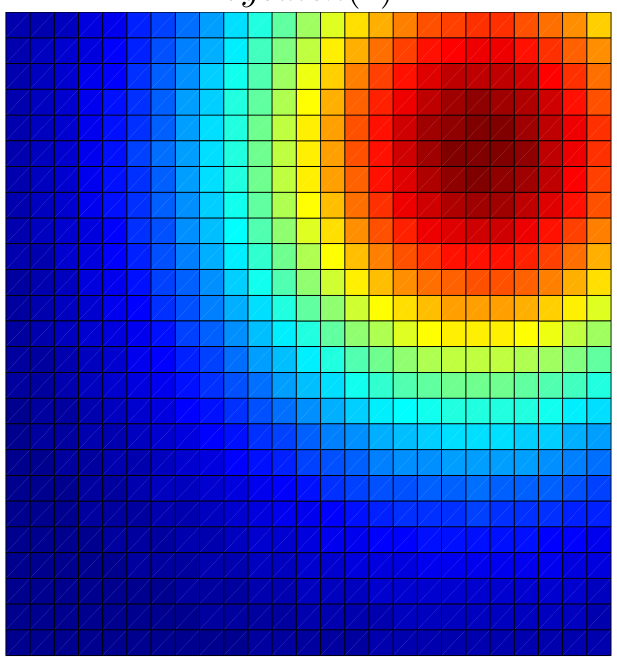




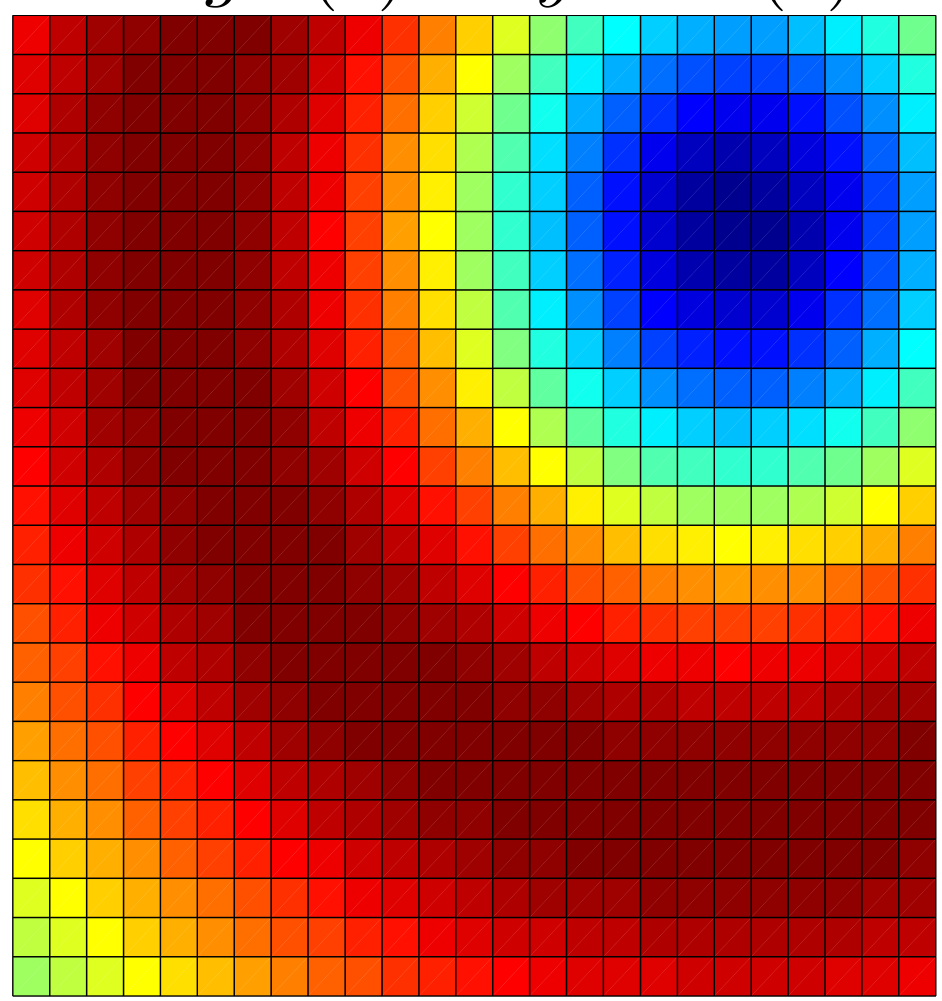
Simulation Model

$$Two\ Species: bycatch(1)\ and\ target(2)$$

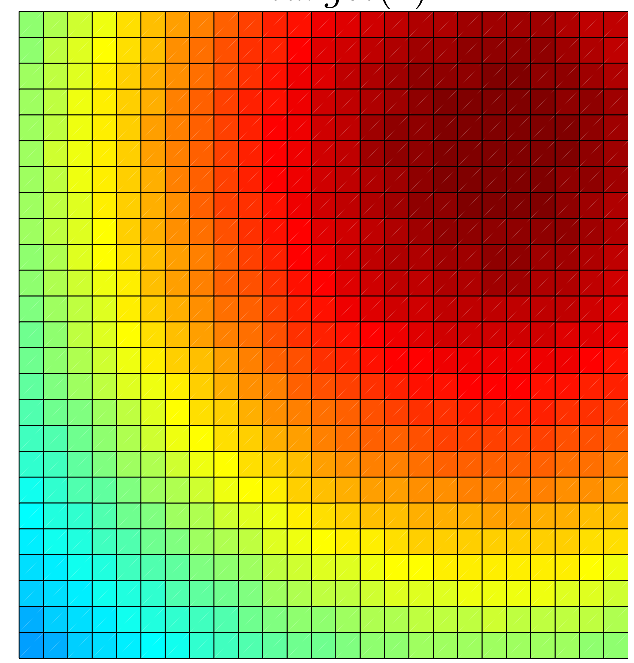
$bycatch(1)$



$target(2) - bycatch(1)$

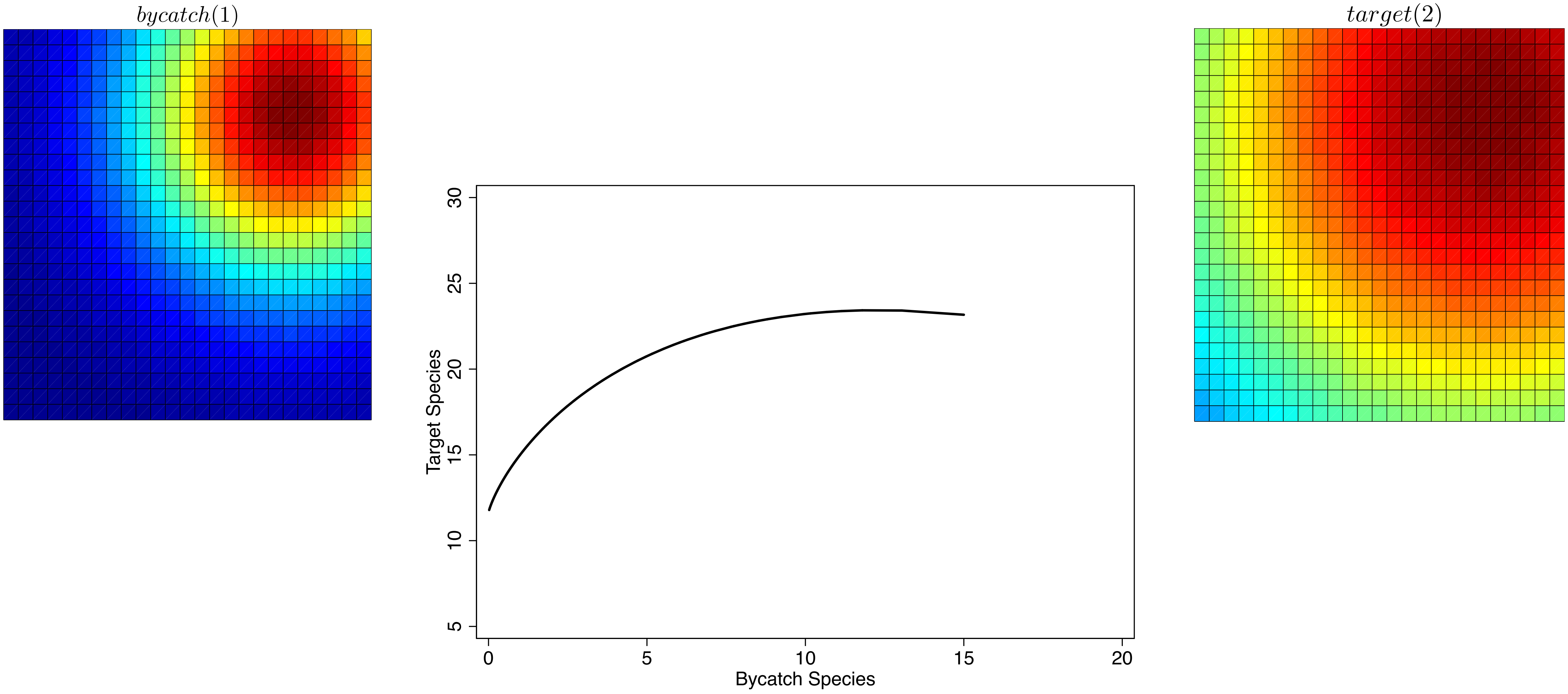


$target(2)$



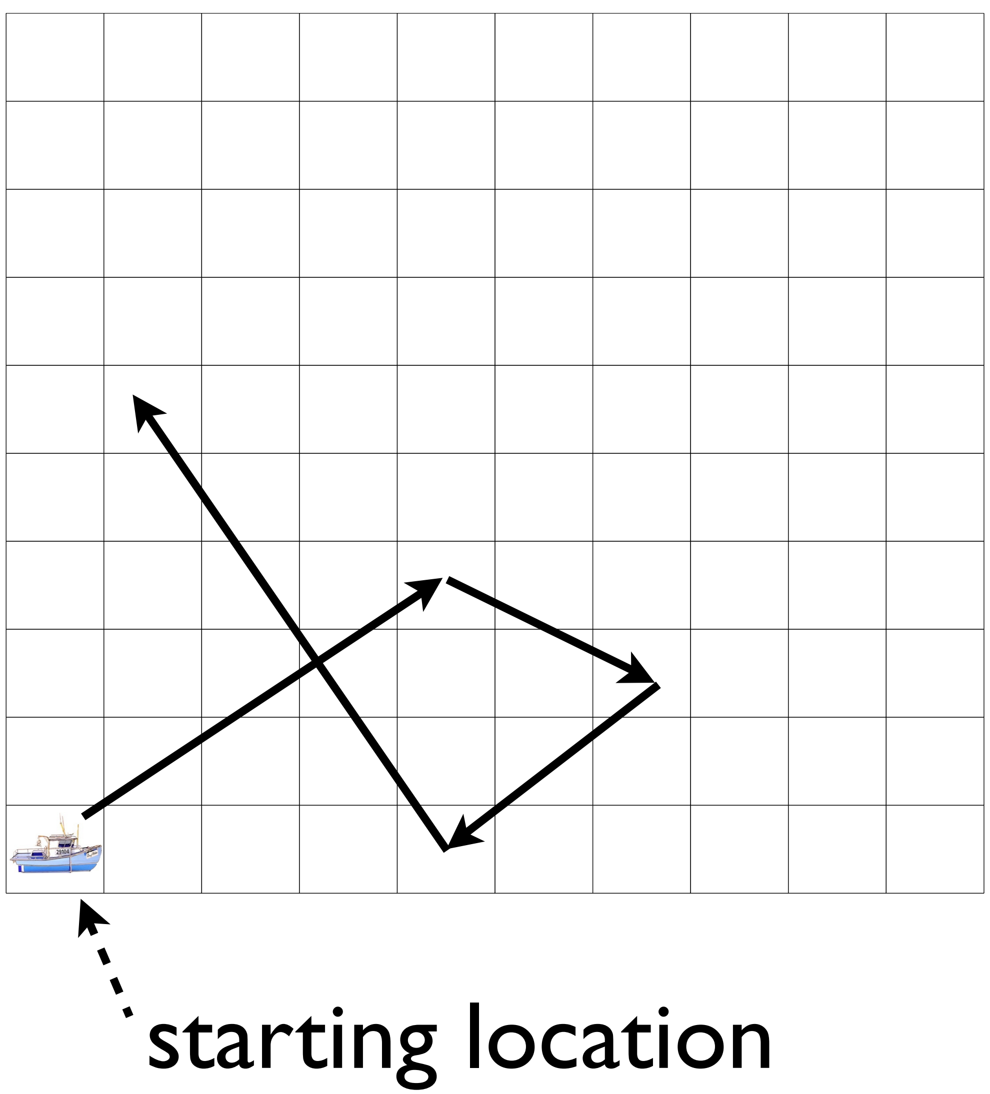
Simulation Model

$$Two\ Species : bycatch(1)\ and\ target(2)$$



Simulation Model

$$At\ each\ t: \qquad \max_{j \in \{1,\ldots J\}} \{E[y_{2tj}] - \rho E[y_{1tj}] - rD_t(j)\}$$



$D_t(j) = distance\ to\ j\ from\ current\ location$

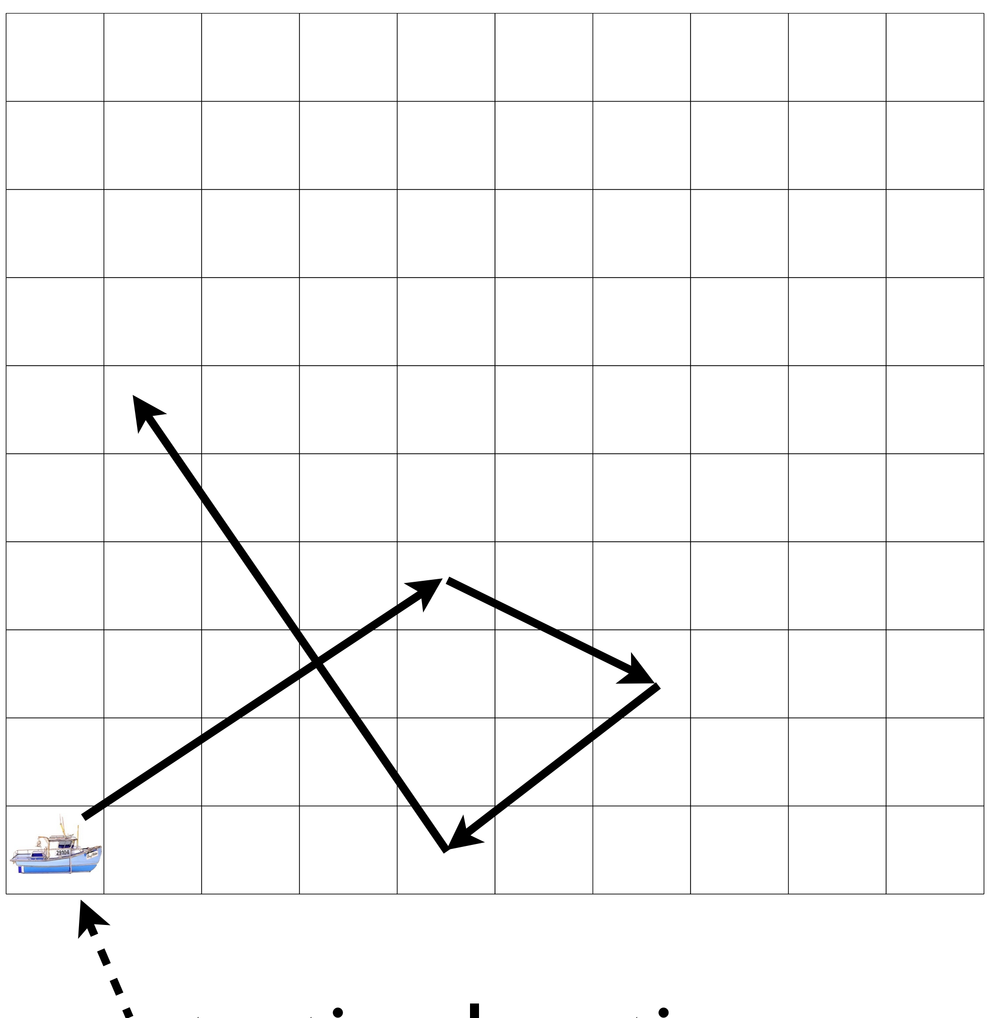
ρ and r are institutional parameters

$$\rho = shadow\ cost\ of\ bycatch$$

low ρ means fishermen do not internalize the external cost of bycatch.

Simulation Model

$$At\ each\ t: \qquad \max_{j \in \{1,\ldots J\}} \{E[y_{2tj}] - \rho E[y_{1tj}] - r D_t(j)\}$$



starting location

$$D_t(j) = distance\ to\ j\ from\ current\ location$$

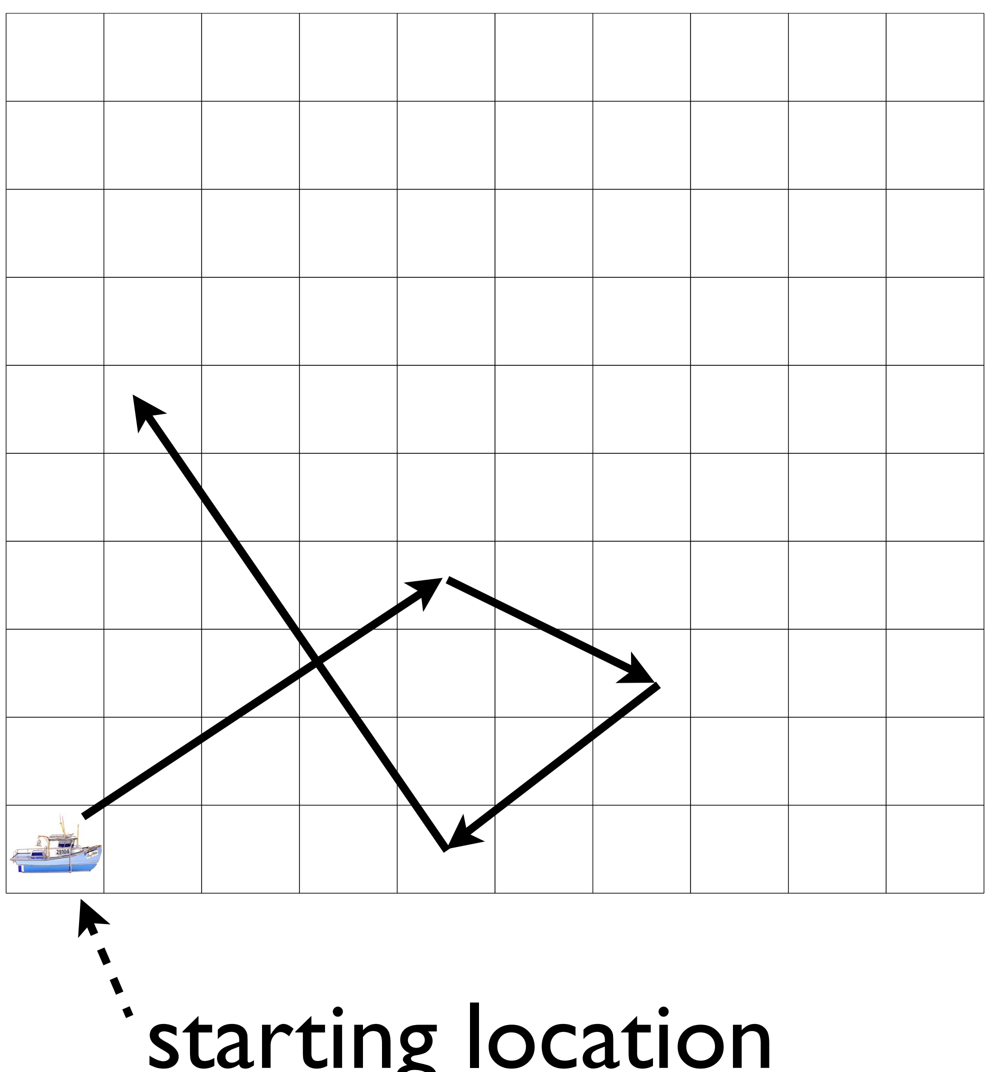
ρ and r are institutional parameters

$$r = shadow\ cost\ of\ travel$$

high r means fishermen perceive an opportunity cost of not fishing.

Simulation Model

$$At\ each\ t: \qquad \max_{j \in \{1,\ldots J\}} \{E[y_{2tj}] - \rho E[y_{1tj}] - rD_t(j)\}$$

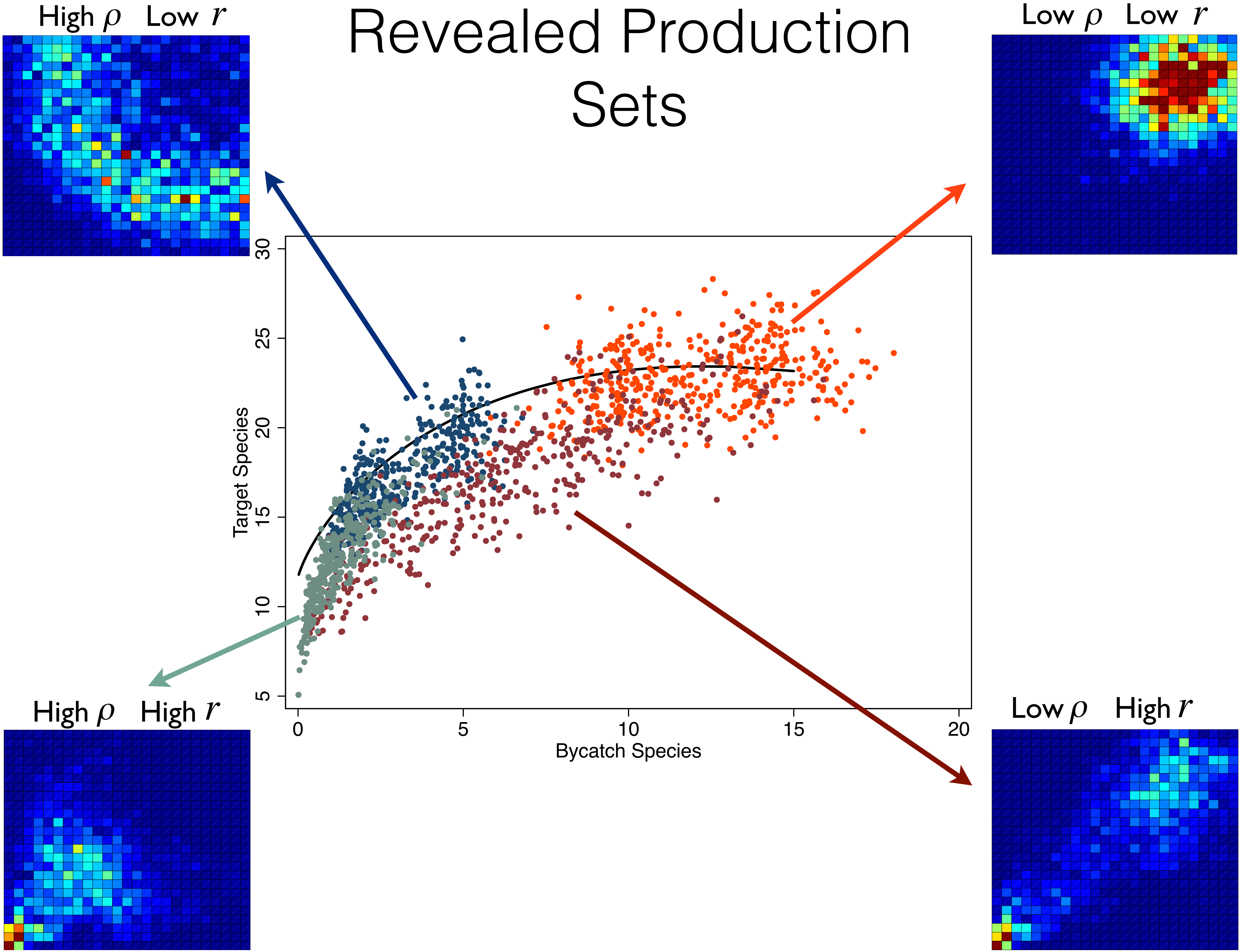


Example

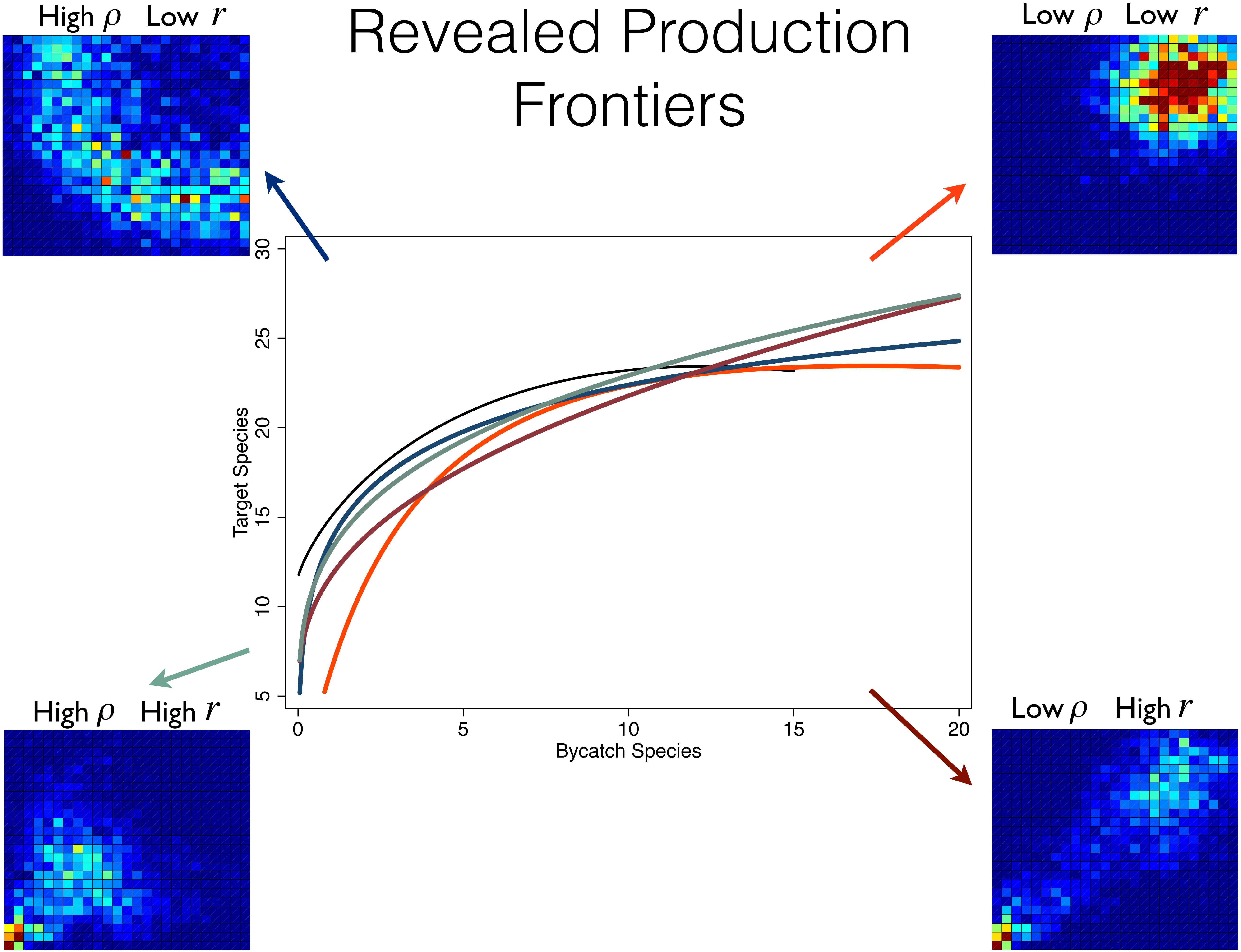
high ρ and low r represents a fishery with catch shares.

low ρ and high r represents a fishery without catch shares.

Revealed Production Sets



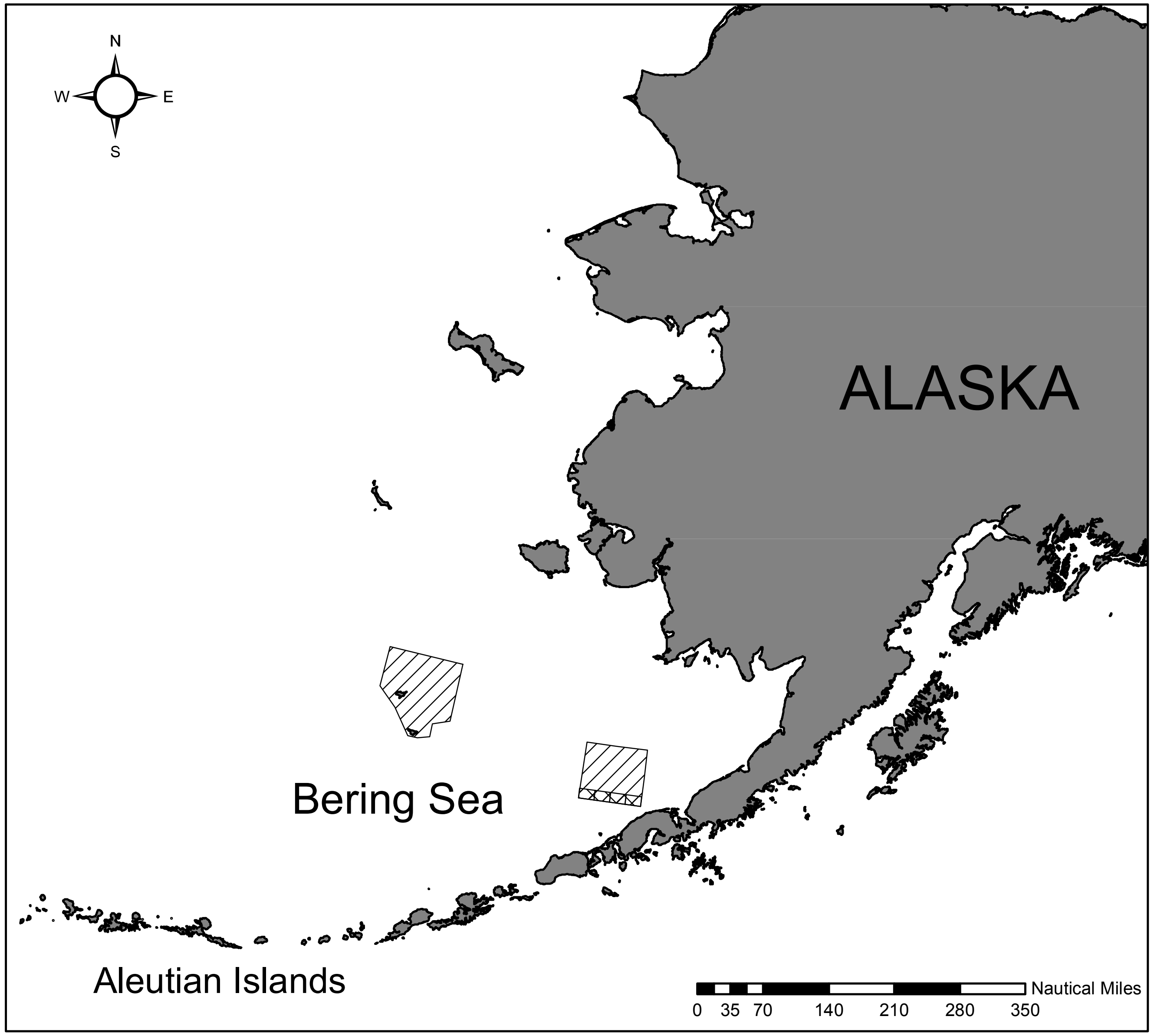
Revealed Production Frontiers

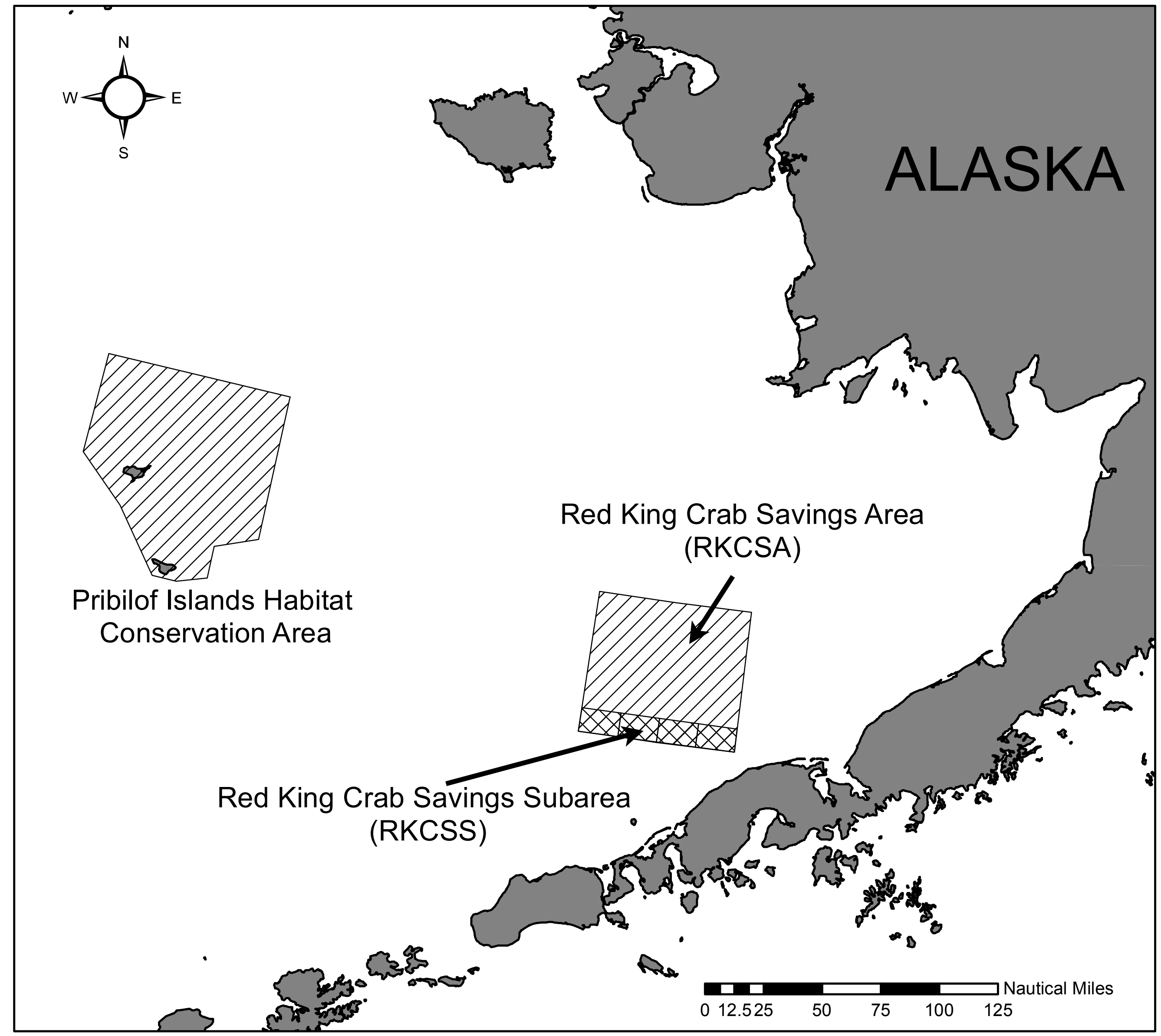


Application: The Bering Sea Groundfish Fishery

Did rights-based management induce bycatch avoidance?

Bering Sea and Aleutian Islands



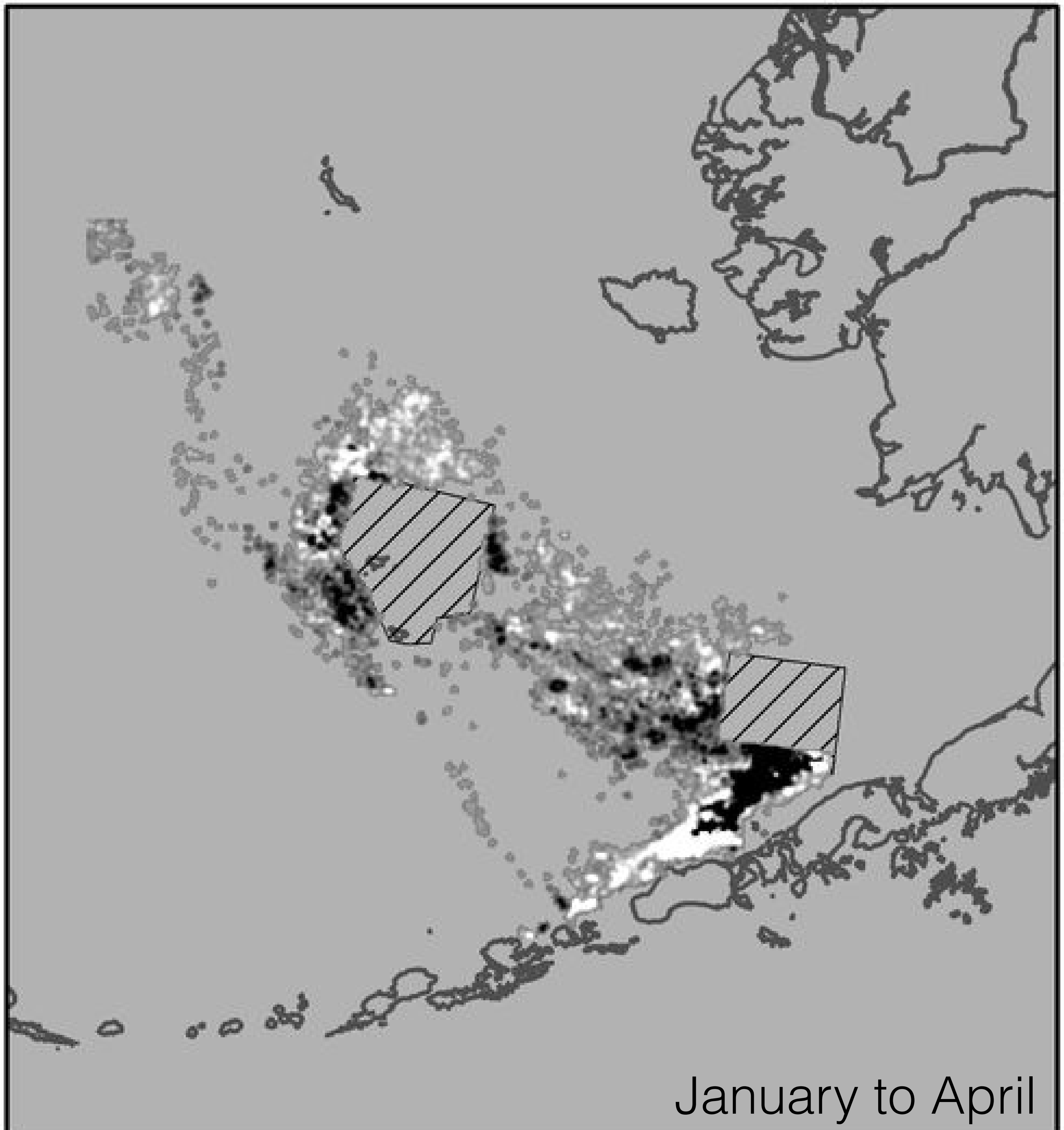


The Bering Sea Groundfish Fishery

- Pre-Amendment 80 (prior to 2008):
  - Target species TACs allocated as common property over multiple “sub-seasons”
  - TAC for prohibited species allocated to target species fisheries
  - Target fisheries typically closed due to binding bycatch TAC
    - particularly true for halibut
  - Fishermen “unable” to avoid halibut

- Post-Amendment 80 (2008 and after):
  - Target species and bycatch allocations vested directly into cooperatives or limited access fishery
  - Initially one cooperative formed: 16 vessels, 7 companies

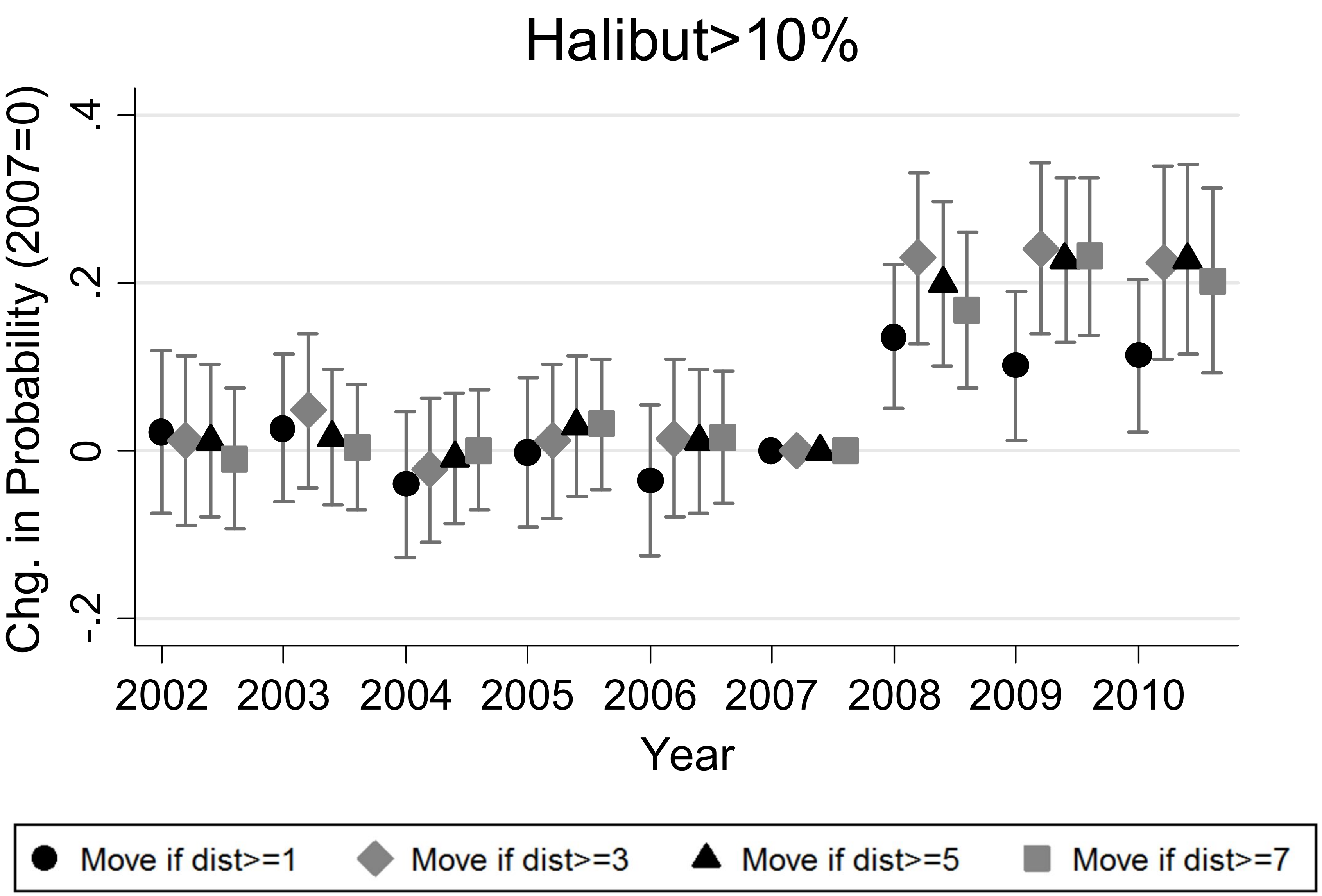
Changes in Fishing Practices



- Large-scale shift in effort away from halibut-rich areas

- Dark = increased effort
- Light = decreased effort

Changes in Fishing Practices



- Fine-scale shift in effort after hauls with a large proportion of halibut

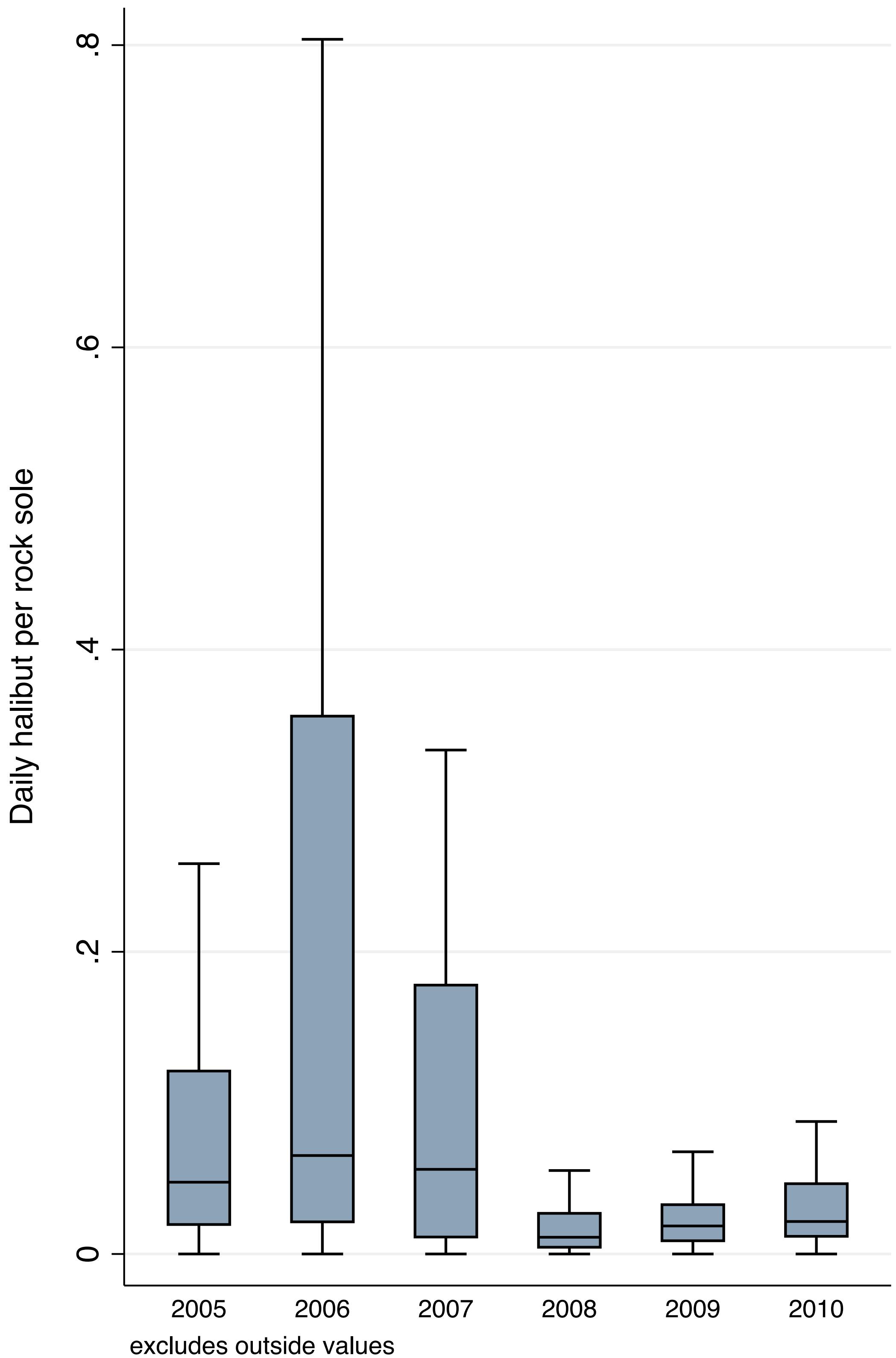
- Probability of moving fishing locations after a large halibut encounter (relative to 2007)

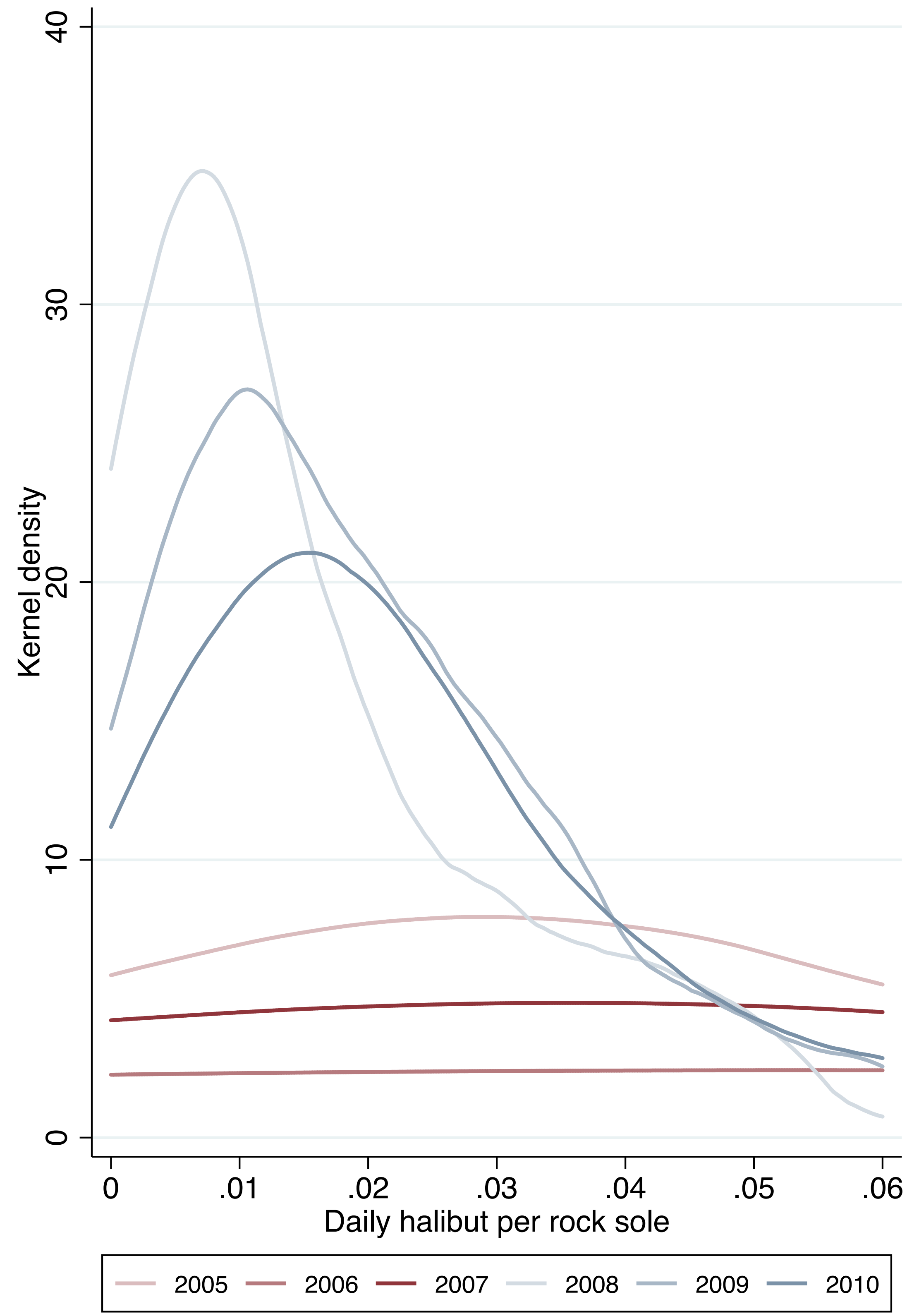
Changes in Fishing Practices

	Full Season		January - April		May - August		September - December	
	Odds Ratio	Marg. Effect	Odds Ratio	Marg. Effect	Odds Ratio	Marg. Effect	Odds Ratio	Marg. Effect
2002	1.019	0.004	1.083	0.018	1.016	0.003	1.146	0.032
	(0.56)	(0.56)	(1.61)	(1.61)	(0.33)	(0.33)	(1.31)	(1.33)
2003	1.059	0.011	1.133*	0.029*	0.985	-0.002	1.195	0.042
	(1.69)	(1.70)	(2.45)	(2.45)	(-0.34)	(-0.34)	(1.62)	(1.64)
2004	1.062	0.011	1.145**	0.031**	0.984	-0.003	1.104	0.024
	(1.76)	(1.76)	(2.66)	(2.67)	(-0.38)	(-0.38)	(0.84)	(0.84)
2005	1.069	0.013	1.112*	0.024*	1.016	0.003	0.870	-0.035
	(1.93)	(1.94)	(2.17)	(2.18)	(0.35)	(0.35)	(-1.10)	(-1.10)
2006	1.024	0.005	1.070	0.015	0.933	-0.011	1.096	0.022
	(0.65)	(0.65)	(1.35)	(1.35)	(-1.40)	(-1.40)	(0.56)	(0.56)
2008	0.775***	-0.049***	0.690***	-0.081***	0.742***	-0.043***	1.083	0.019
	(-6.69)	(-6.65)	(-5.89)	(-5.95)	(-5.62)	(-5.43)	(0.79)	(0.79)
2009	0.799***	-0.044***	0.742***	-0.067***	0.782***	-0.067***	1.066	0.015
	(-5.44)	(-5.43)	(-4.58)	(-4.61)	(-4.17)	(-4.61)	(0.61)	(0.62)
2010	0.758***	-0.055***	0.796***	-0.051***	0.710***	-0.05***	0.884	-0.029
	(-6.75)	(-6.73)	(-3.58)	(-3.60)	(-5.03)	(-5.06)	(-1.17)	(-1.16)
N	18,260		7,461		8,010		2,789	

- Shift away from night-fishing
  - Halibut more abundant during night-time hours

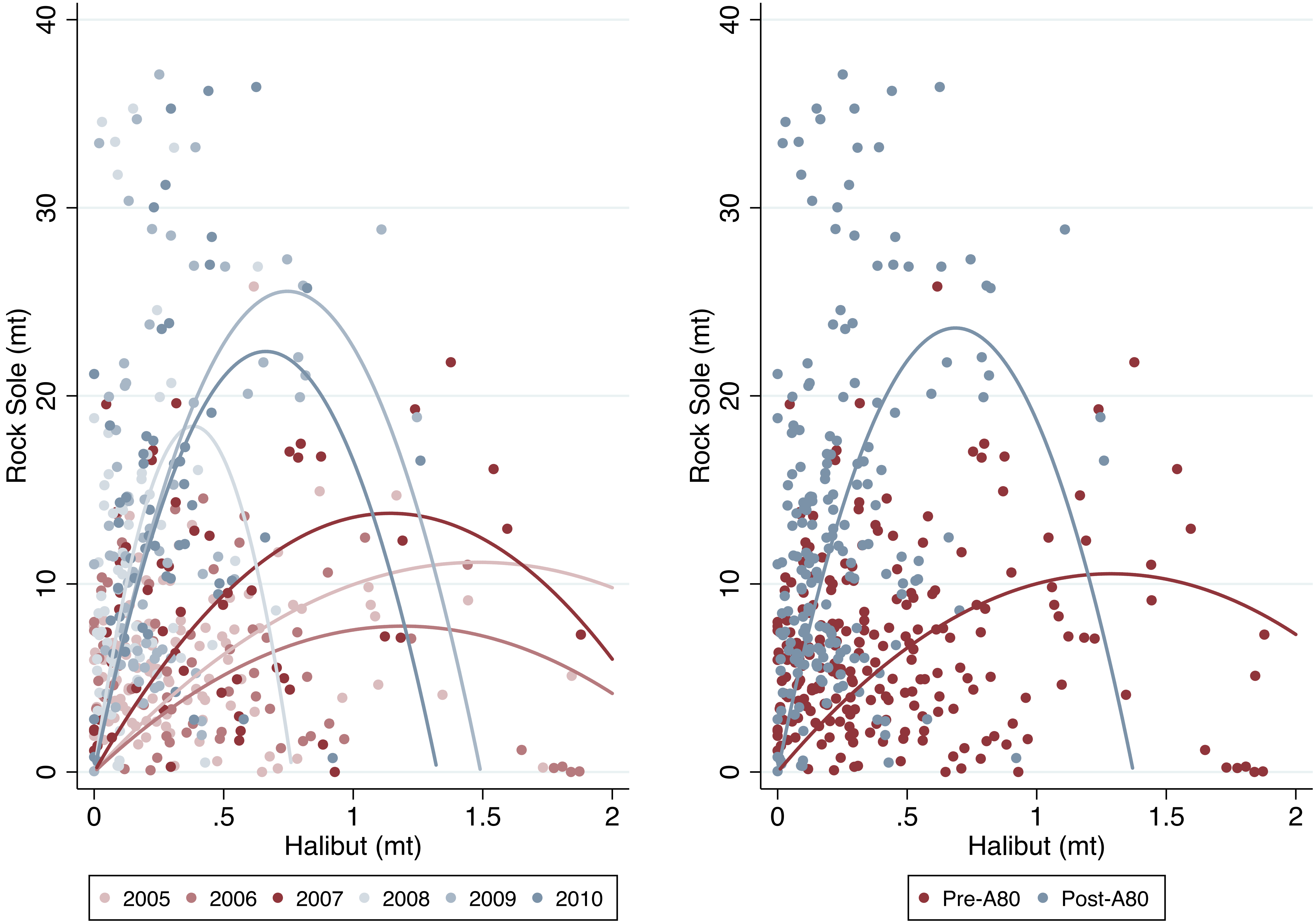
Changes in Bycatch Intensity





January-April

Changes in Bycatch Intensity



January-April

Estimating Fishing Production Function

- A Hyperbolic Distance Function Approach

Transformation Function: $T(x, y, b) = 0$

inputs $y =$ *good outputs* $b =$ *bad outputs*

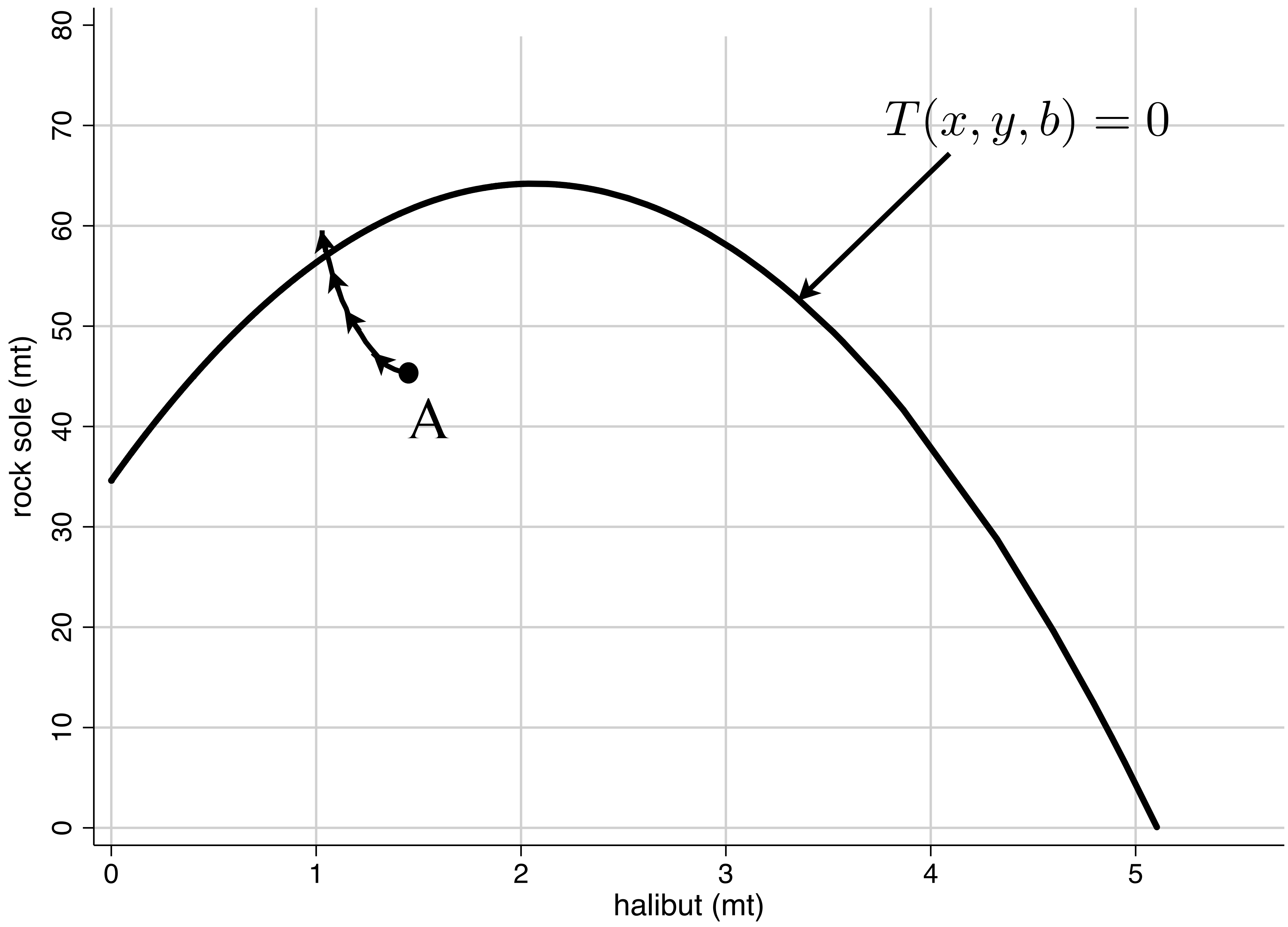
Hyperbolic Output Distance Function:

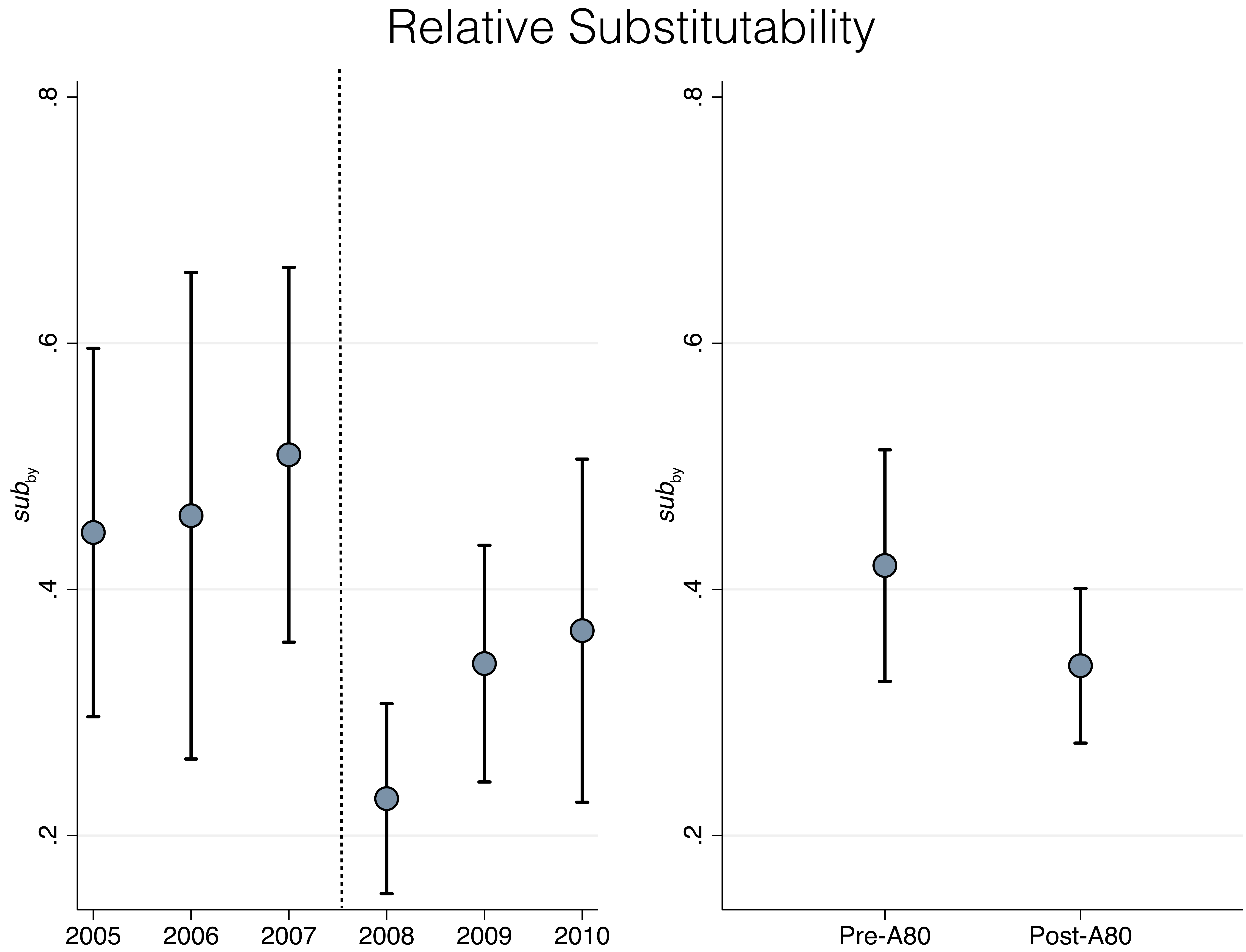
$$D^H(x, y, b) = \min_{\theta} \{\theta > 0 : T(x, y/\theta, b\theta) \leq 0\}$$

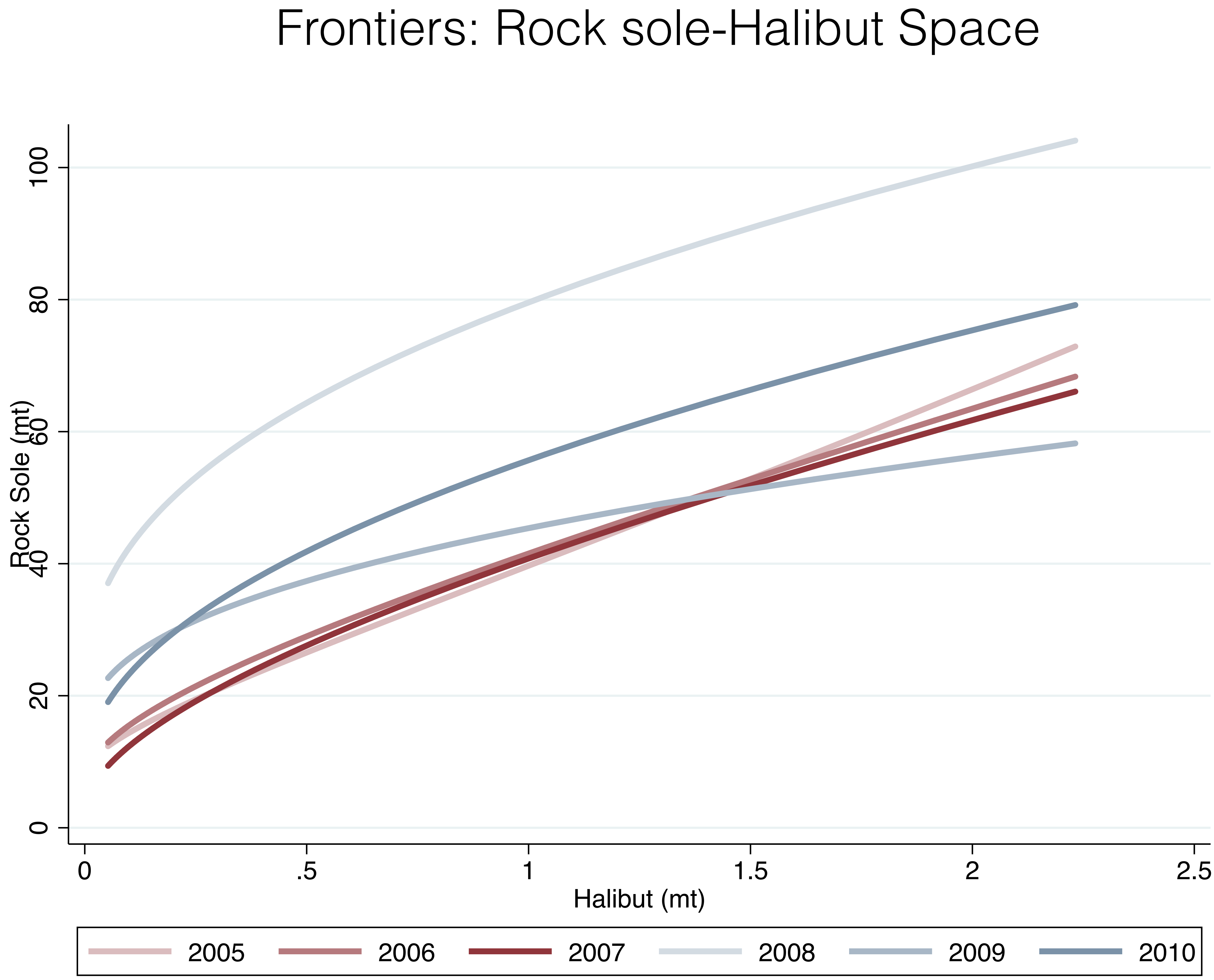
$$0 < D^H(x, y, b) \leq 1$$

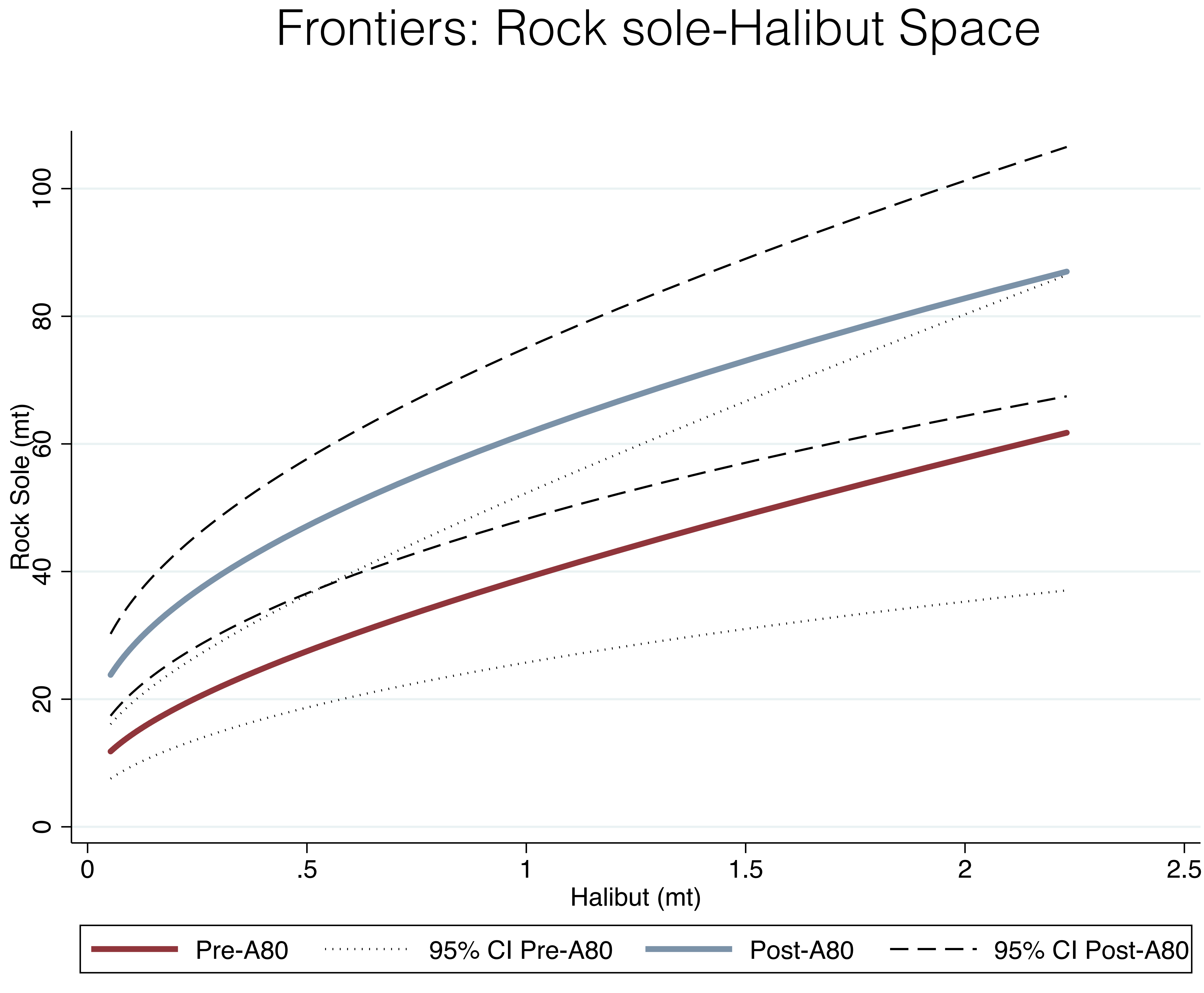
Estimating Fishing Production Function

- A Hyperbolic Distance Function Approach




Relative Substitutability
.8
.6
.4
.2
sub_{by}
2005
2006
2007
2008
2009
2010
Pre-A80
Post-A80


Frontiers: Rock sole-Halibut Space
Rock Sole (mt)
0
20
40
60
80
100
0
.5
1
1.5
2
2.5
Halibut (mt)
2005
2006
2007
2008
2009
2010



Frontiers: Rock sole-Halibut Space
Rock Sole (mt)
0
20
40
60
80
100
0
.5
1
1.5
2
2.5
Halibut (mt)
Pre-A80
95% CI Pre-A80
Post-A80
95% CI Post-A80

Lessons

- Fishermen substantially altered catch compositions in a complex multispecies fishery:
    - Multiple margins of behavior: e.g. macro-location choices, micro-spatial responses, reduced night-time fishing
    - Substitution potential was latent until management changes altered *incentives*

- Pre-A80 production frontier considerably different from post-A80 frontier:
    - Estimated production relationship is a function of technology, biology, and behavioral incentives
    - Highlights the difficulty in assessing the potential for cross-species substitution in fisheries using *ex ante* data alone

Moving Forward….

- Ex ante predictions require greater care be given to modeling fishing as a process:
  - Information derived from micro-data
  - Production models are context-specific
  - Conversations with fishermen to understand fundamental decisions
  - May not map perfectly into notion of “conventional inputs”

- Greater structure needed for models of behavior:
  - Nest fishing decisions in a structural economic (i.e. optimization) model to identify “deep” parameters that are invariant to policy intervention
  - More demanding in terms of time, data, and assumptions

Examples

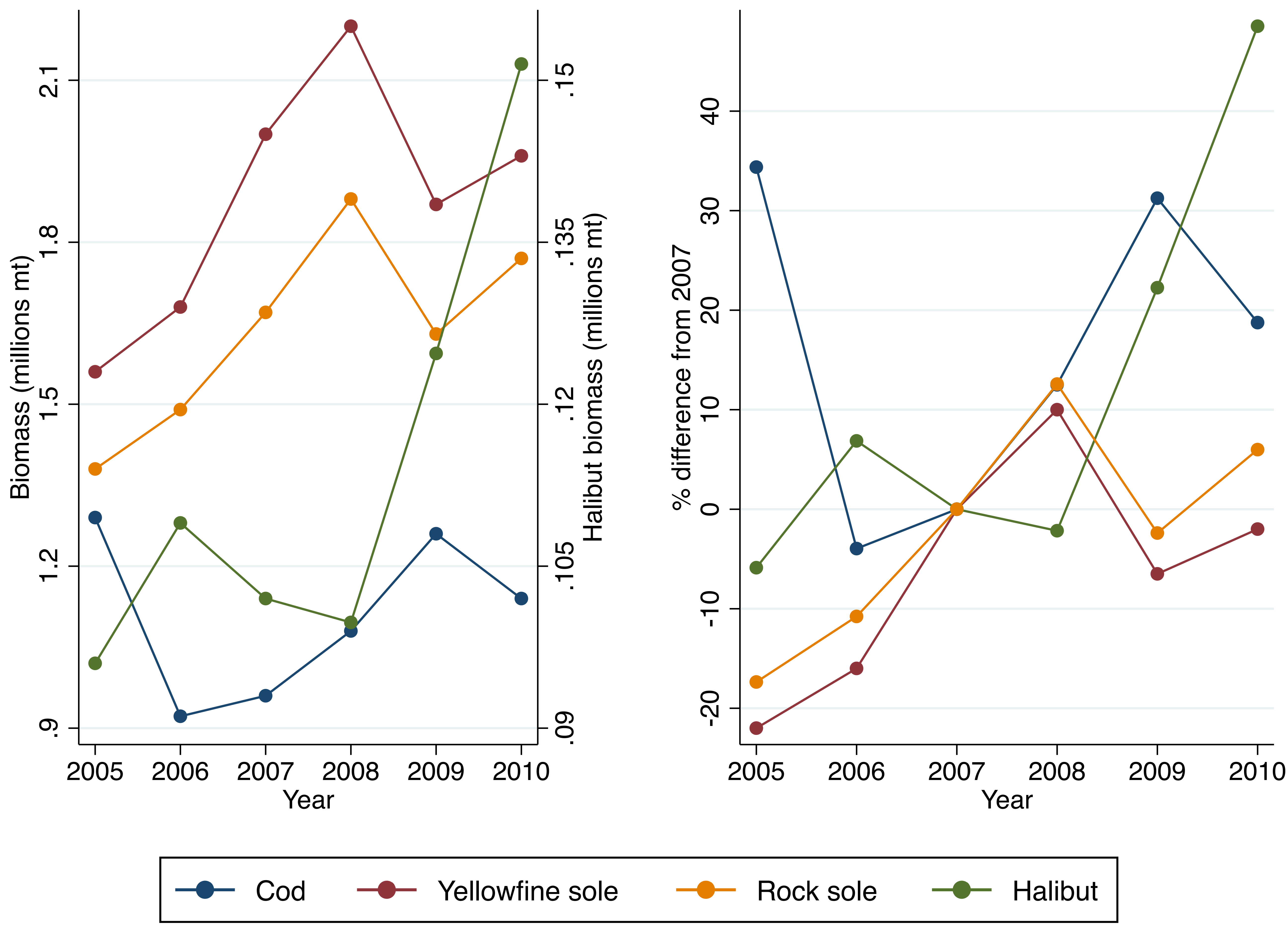
- Predicting the behavioral response to a spatial closure (Smith and Wilen, 2003):
    - Estimate spatial behavior as a function of location-specific characteristics using *ex ante* data
    - Identify behavioral parameters that can be transported to a setting with only a subset of locations to choose from
    - Key: incentives stayed the same with only a change in constraints

- Predicting the behavioral response to ITQs (Reimer et al., 2014)
    - Predict response to ITQs in Alaska red king crab fishery using *ex ante* data
    - Key: requires optimization under different pre- and post-incentive structures

To Conclude….

- Accurate assessment of the impacts of a policy requires a description of the production process that is sufficiently "deep" so as to be invariant to changes in management institutions

"*Without detailed and accurate prediction of firms' response to policies, regulations can have unexpected and adverse results*." (Bockstael and Opaluch, 1983)



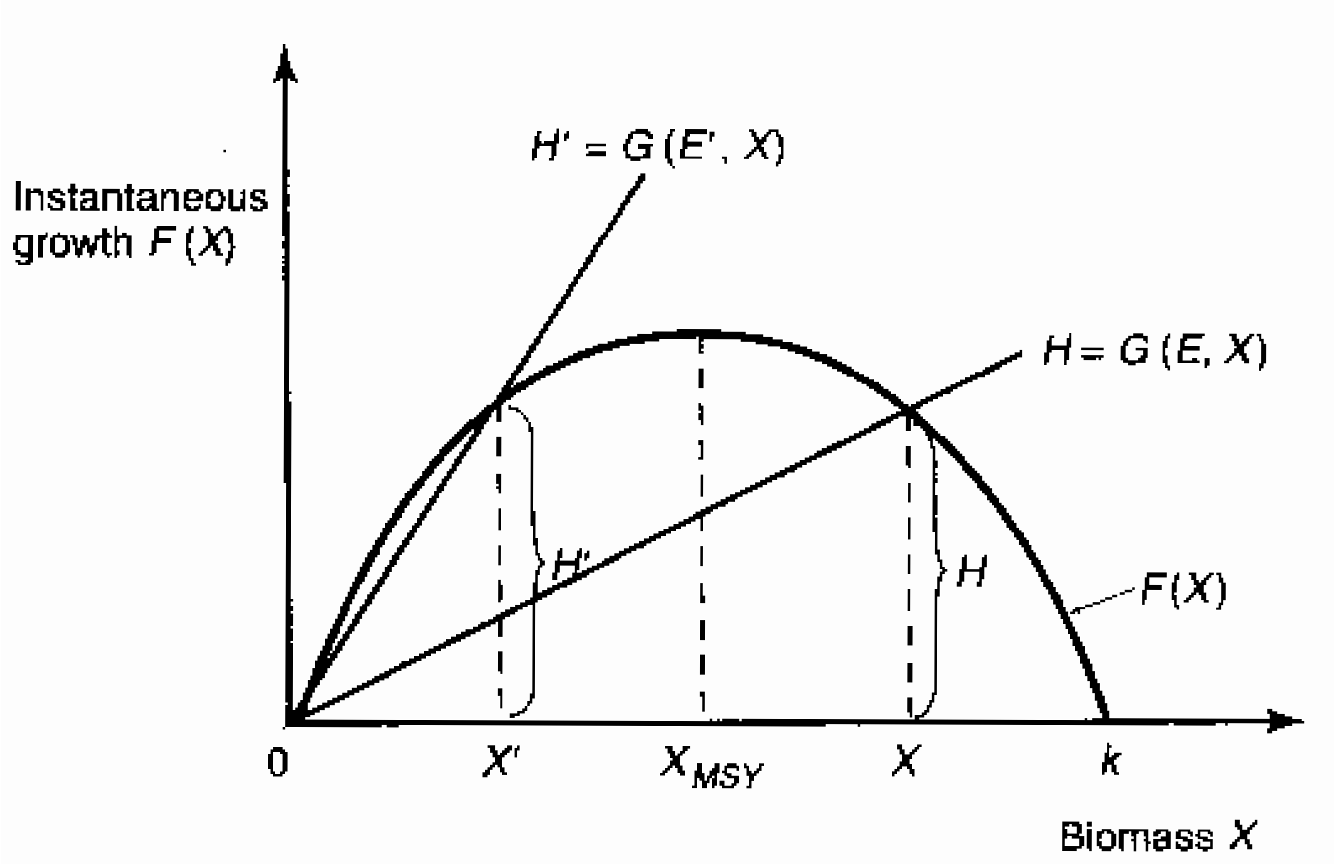
Biomass (millions mt)
Halibut biomass (millions mt)
% difference from 2007
Year
Year
Cod
Yellowfine sole
Rock sole
Halibut

Production Models in Fisheries

- Earliest models: $y = qEX$

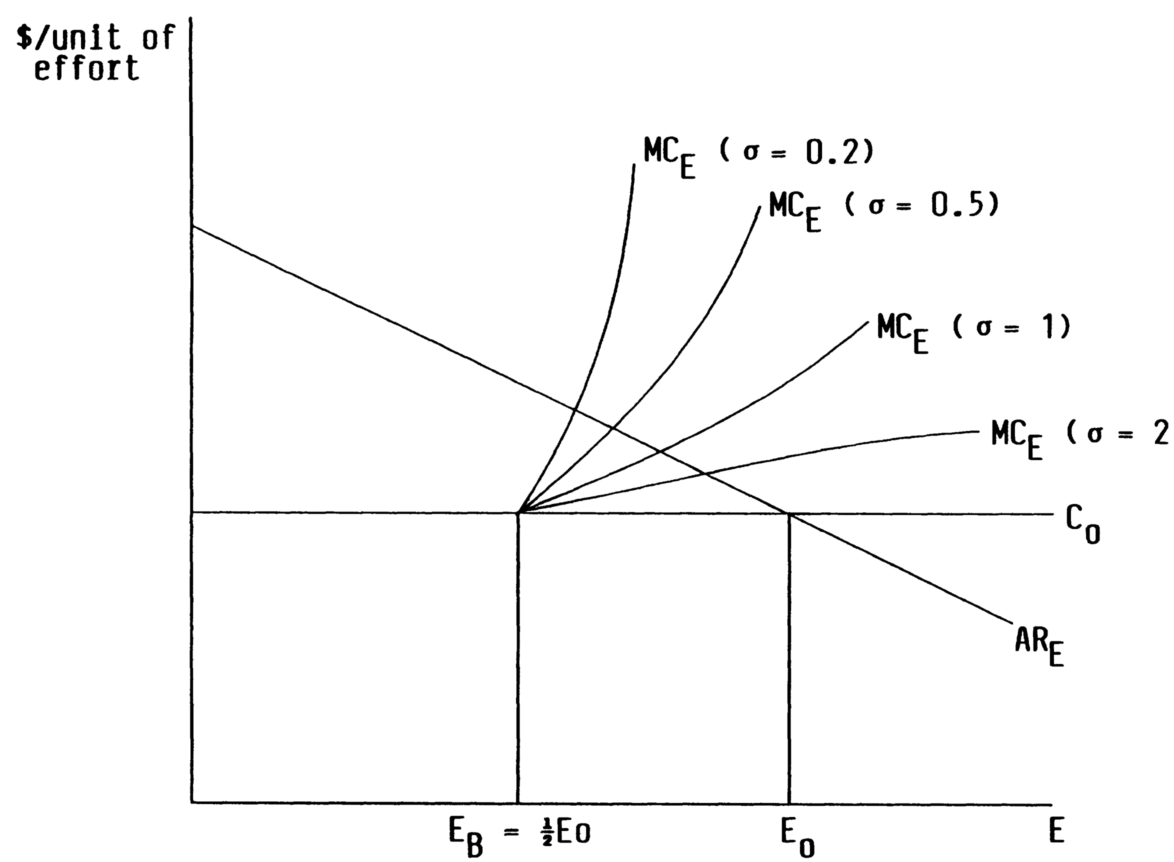
Combined with a surplus production model, this simple harvest function led to some important insights:

- Open access and rent dissipation (Gordon, 1954; Smith, 1969)
- Sole ownership (Scott, 1955)
- Regulated open access (Homans and Wilen, 1997)
- General lesson: solve the open access problem by limiting entry



Production Models in Fisheries

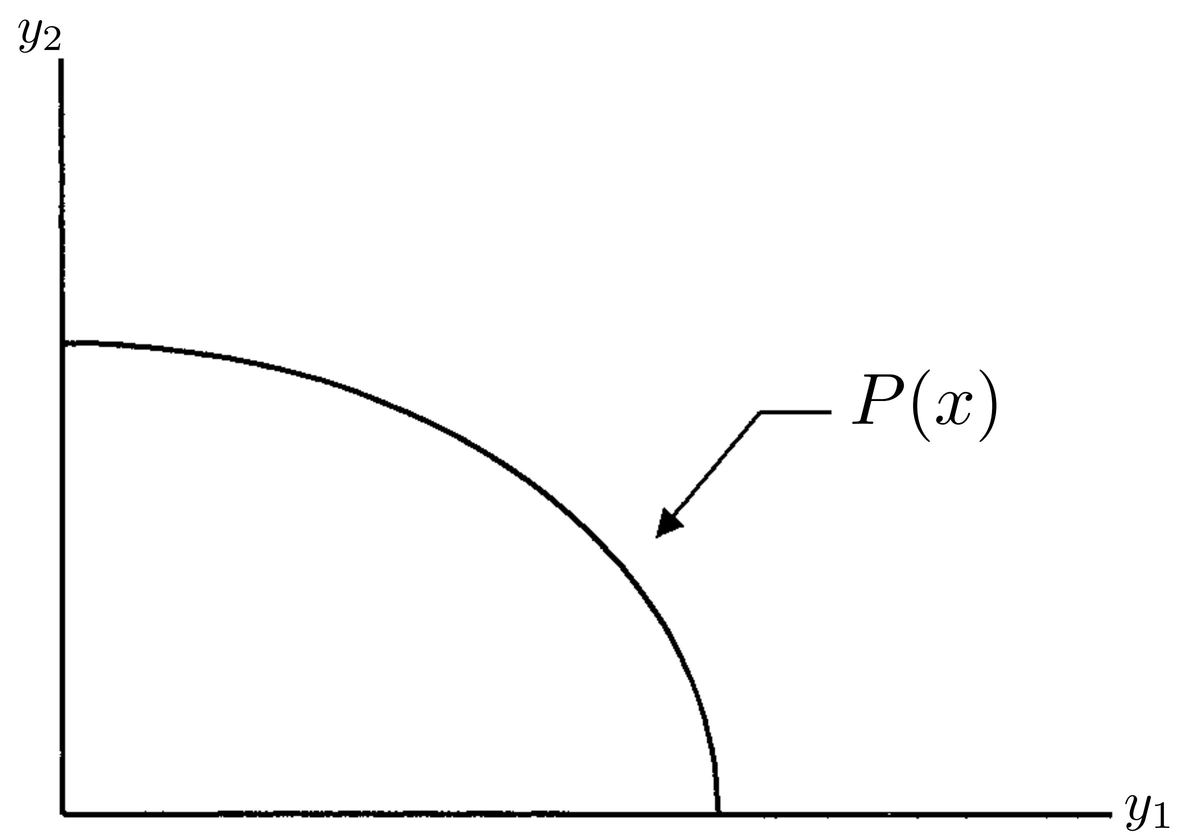
- Expanding the index effort: $E = E(\mathbf{x}_f, \mathbf{x}_v) \quad y = f(E(\mathbf{x}_f, \mathbf{x}_v); X)$
  - Rent dissipation along unregulated effort dimensions under limited entry highlighted the inadequacy of single index effort models to depict fishing behavior.
  - Multi-input effort models emerged, demonstrating that rent dissipation under input control regulations depended on substitutability between regulated and unregulated inputs (Anderson, 1985; Squires, 1987; Campbell and Lindner, 1990; Dupont, 1991)

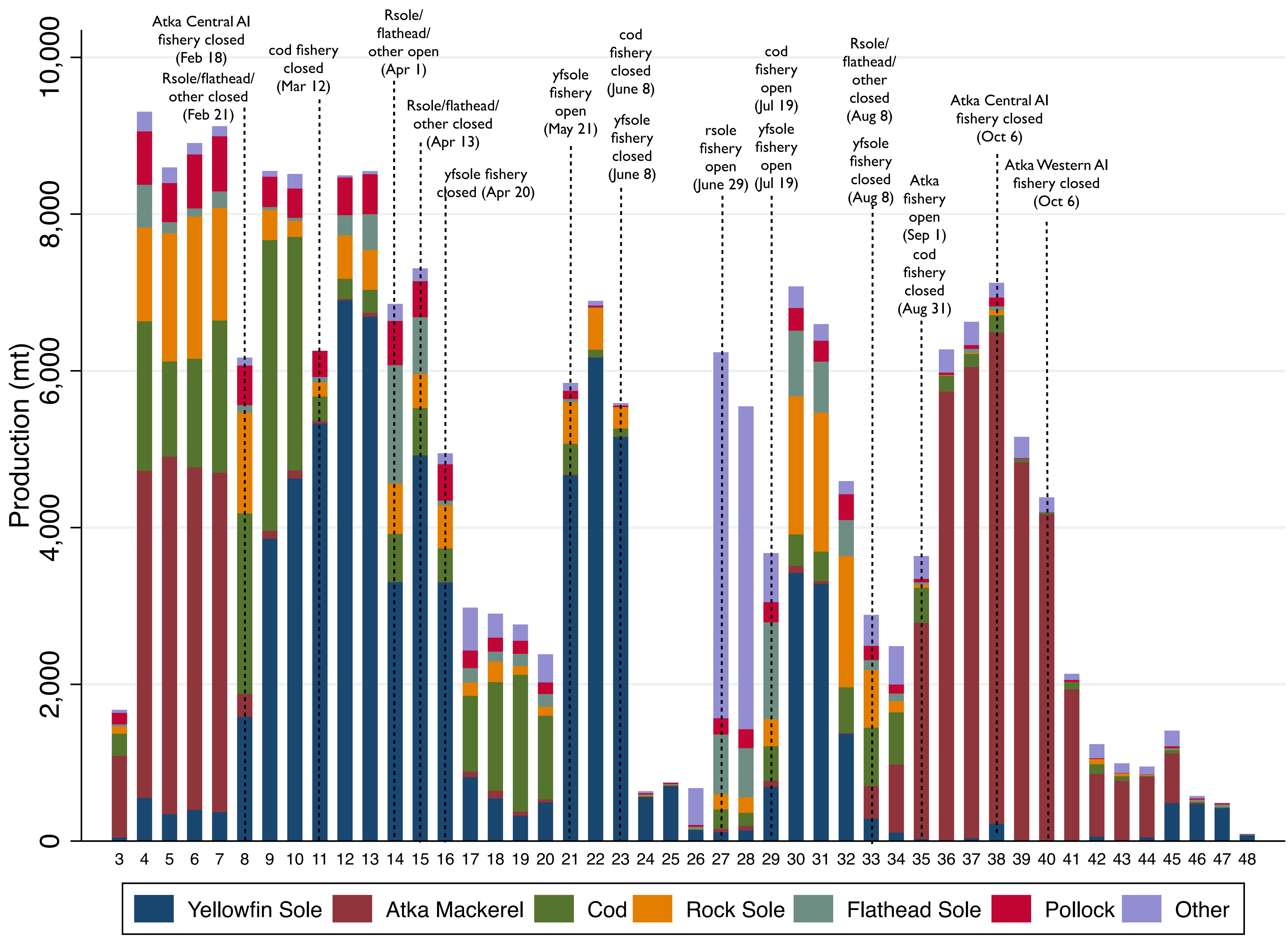


Production Models in Fisheries

- Expanding the index catch: $P(\mathbf{x}) = \{\mathbf{y} : T(\mathbf{x}, \mathbf{y}) \leq 0\}$

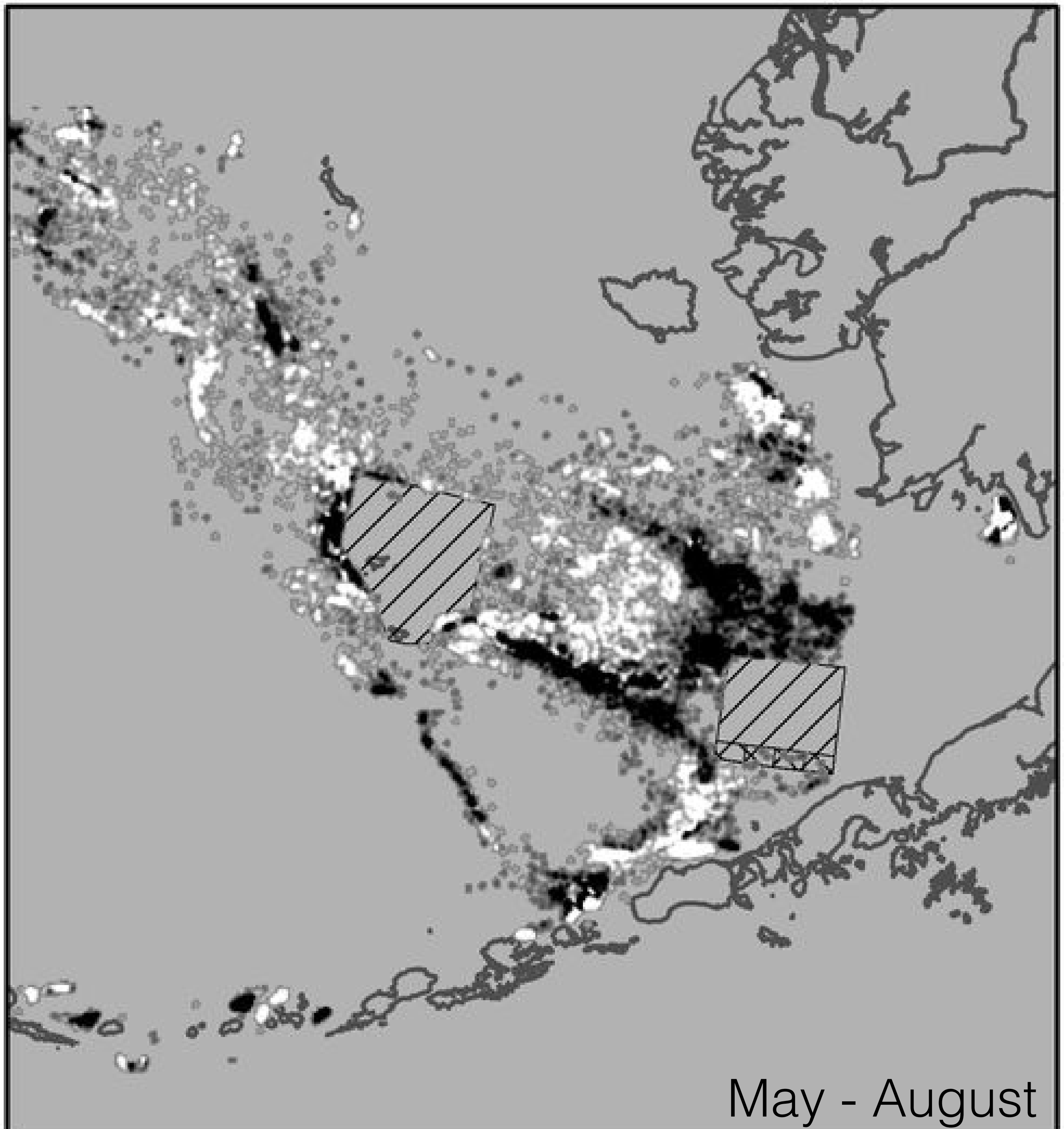
- Single output production models ignored the multi-species component of fisheries, imposing input-output separability and/or nonjointness in inputs
- Multi-output models emerged characterizing output substitutability:
    - Dual formulations (Squires, 1987; Kirkley and Strand 1988)
    - Primal Formulations (Felthoven and Morrison Paul, 2004)





Atka Central AI fishery closed (Feb 18)
Rsole/flathead/ other closed (Feb 21)
cod fishery closed (Mar 12)
Rsole/ flathead/ other open (Apr 1)
Rsole/flathead/ other closed (Apr 13)
yfsole fishery closed (Apr 20)
yfsole fishery open (May 21)
cod fishery closed (June 8)
yfsole fishery closed (June 8)
rsole fishery open (June 29)
cod fishery open (Jul 19)
yfsole fishery open (Jul 19)
Rsole/ flathead/ other closed (Aug 8)
yfsole fishery closed (Aug 8)
Atka fishery open (Sep 1)
cod fishery closed (Aug 31)
Atka Central AI fishery closed (Oct 6)
Atka Western AI fishery closed (Oct 6)
Production (mt)
0
2,000
4,000
6,000
8,000
10,000
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
Yellowfin Sole
Atka Mackerel
Cod
Rock Sole
Flathead Sole
Pollock
Other

Changes in Fishing Practices



- Large-scale shift in effort away from halibut- and cod-rich areas

- Dark = increased effort
- Light = decreased effort

Abbott, Haynie, and Reimer (In press)