Bycatch Avoidance under Cooperative Management

R Christopher Martin
UW

Dan Holland
NOAA NWFSC
Outline

1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
   - Analytical Model: quota-based management creates incentives that almost certainly don’t align with the social planner’s loss function.
Outline

1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
   - Analytical Model: quota-based management creates incentives that almost certainly don’t align with the social planner’s loss function.
   - Empirical Context: evidence that cooperatives are effectively inducing bycatch avoidance.

2. The Pacific Whiting Fishery

3. Model sketch

4. Empirical analysis of Bycatch Rates & Avoidance Behavior under cooperative management
Outline

1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
   ▶ Analytical Model: quota-based management creates incentives that almost certainly don’t align with the social planner’s loss function.
   ▶ Empirical Context: evidence that cooperatives are effectively inducing bycatch avoidance.

2. The Pacific Whiting Fishery
1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
   - Analytical Model: quota-based management creates incentives that almost certainly don’t align with the social planner’s loss function.
   - Empirical Context: evidence that cooperatives are effectively inducing bycatch avoidance.

2. The Pacific Whiting Fishery

3. Model sketch
Outline

1. Guiding question: what challenges do stochastic and lumpy bycatch pose to quota-based management?
   ▶ Analytical Model: quota-based management creates incentives that almost certainly don’t align with the social planner’s loss function.
   ▶ Empirical Context: evidence that cooperatives are effectively inducing bycatch avoidance.

2. The Pacific Whiting Fishery

3. Model sketch

4. Empirical analysis of Bycatch Rates & Avoidance Behavior under cooperative management
West Coast Catch Share Program Failure Keeps Vessel Off Fishing Grounds for 2016 Season


Criticism that the West Coast catch shares program is underperforming came to the forefront recently at the Pacific Fishery Management Council meeting in Sacramento.

West Coast trawlers have been operating in fear of a "disaster tow" or "lightning strike" of a choke species since the beginning of the individual quota program in 2011. And for the F/V Seeker, a disaster tow of 47,000 pounds of canary rockfish – a species at the time listed as overfished -- in November 2015 will prevent it from fishing for all of 2016.
Related Literature

- Most theoretical literature uses a deterministic joint production function, following Boyce (1996).


Holland (2010) considers management when bycatch production is stochastic and "lumpy", characteristics that describe certain west coast fisheries.

If vessels can imperfectly control their exposure to bycatch through costly avoidance behavior, all potentially binding species may affect early-season fishing behavior even if the quota are non-binding at the end of the season.
Related Literature

- Most theoretical literature uses a deterministic joint production function, following Boyce (1996).
  - Upshot: positive shadow value for constraining species, while other species are slack.


- Holland (2010) considers management when bycatch production is stochastic and "lumpy", characteristics that describe certain west coast fisheries.

- If vessels can imperfectly control their exposure to bycatch through costly avoidance behavior, all potentially binding species may affect early-season fishing behavior even if the quota are non-binding at the end of the season.
Related Literature

- Most theoretical literature uses a deterministic joint production function, following Boyce (1996).
  - Upshot: positive shadow value for constraining species, while other species are slack.
- Holland (2010) considers management when bycatch production is stochastic and "lumpy", characteristics that describe certain west coast fisheries.
  - If vessels can imperfectly control their exposure to bycatch through costly avoidance behavior, all potentially binding species may affect early-season fishing behavior even if the quota are non-binding at the end of the season.
Related Literature

- Most theoretical literature uses a deterministic joint production function, following Boyce (1996).
  - Upshot: positive shadow value for constraining species, while other species are slack.
- Holland (2010) considers management when bycatch production is stochastic and “lumpy”, characteristics that describe certain west coast fisheries.
Related Literature

- Most theoretical literature uses a deterministic joint production function, following Boyce (1996).
  - Upshot: positive shadow value for constraining species, while other species are slack.
- Holland (2010) considers management when bycatch production is stochastic and “lumpy”, characteristics that describe certain west coast fisheries.
- If vessels can imperfectly control their exposure to bycatch through costly avoidance behavior, all potentially binding species may affect early-season fishing behavior even if the quota are non-binding at the end of the season.
Three non-tribal sectors/fleets: Catcher-Processors (CP, 34%, 5–9 vessels), Mothership-Catcher Vessels (MSCV, 24%, 4–6 motherships, 10–23 catcher-vessels), and Shoreside Catcher Vessels (SS, 42%, 29–40 vessels). CP/MSCV fleets are collectively known as the at-sea fishery.
Introduction to Pacific Whiting Fishery

- Three non-tribal sectors/fleets: Catcher-Processors (CP, 34%, 5–9 vessels), Mothership-Catcher Vessels (MSCV, 24%, 4–6 motherships, 10–23 catcher-vessels), and Shoreside Catcher Vessels (SS, 42%, 29–40 vessels). CP/MSCV fleets are collectively known as the at-sea fishery.

- High volume, low value, high quota attainment marginal fishery. Generates contribution profit for pollock fleets (at-sea sector) and Pacific mixed groundfish trawl vessels.
Introduction to Pacific Whiting Fishery

- Sectoral allocations were divided in the late 90s. Species level bycatch caps were instituted in 2005 at the fishery level, apportioned to the fleet level in 2011.
Introduction to Pacific Whiting Fishery

- Sectoral allocations were divided in the late 90s. Species level bycatch caps were instituted in 2005 at the fishery level, apportioned to the fleet level in 2011.

- CP fleet formed a cooperative in the late 90s, MSCV sector in 2011, and SS sector was rationalized in 2011. Many SS vessels formed risk-pool cooperatives for rare and highly variable bycatch, combining their bycatch quota and drawing from a common pool.

Five bycatch species of major concern: Canary, Widow, and Darkblotched Rockfish; Chinook Salmon; Pacific Ocean Perch.
Introduction to Pacific Whiting Fishery

- Sectoral allocations were divided in the late 90s. Species level bycatch caps were instituted in 2005 at the fishery level, apportioned to the fleet level in 2011.
- CP fleet formed a cooperative in the late 90s, MSCV sector in 2011, and SS sector was rationalized in 2011. Many SS vessels formed risk-pool cooperatives for rare and highly variable bycatch, combining their bycatch quota and drawing from a common pool.
- Cooperatives institute enforceable bycatch avoidance rules and information sharing to mitigate moral hazard.

Five bycatch species of major concern: Canary, Widow, and Darkblotched Rockfish; Chinook Salmon; Pacific Ocean Perch
Introduction to Pacific Whiting Fishery

- Sectoral allocations were divided in the late 90s. Species level bycatch caps were instituted in 2005 at the fishery level, apportioned to the fleet level in 2011.

- CP fleet formed a cooperative in the late 90s, MSCV sector in 2011, and SS sector was rationalized in 2011. Many SS vessels formed risk-pool cooperatives for rare and highly variable bycatch, combining their bycatch quota and drawing from a common pool.

- Cooperatives institute enforceable bycatch avoidance rules and information sharing to mitigate moral hazard.

- Five bycatch species of major concern: Canary, Widow, and Darkblotched Rockfish; Chinook Salmon; Pacific Ocean Perch
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
- MS-CV sector divides each season into “pools”, penalty for exceeding bycatch “base rate” for your pool...
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
- MS-CV sector divides each season into “pools”, penalty for exceeding bycatch “base rate” for your pool...
  - only takes effect if that bycatch species shuts down the pool prematurely.
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
- MS-CV sector divides each season into “pools”, penalty for exceeding bycatch “base rate” for your pool...
  - only takes effect if that bycatch species shuts down the pool prematurely.
  - takes the form of reduced participation options later in the season.
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
- MS-CV sector divides each season into “pools”, penalty for exceeding bycatch “base rate” for your pool...
  - only takes effect if that bycatch species shuts down the pool prematurely.
  - takes the form of reduced participation options later in the season.
- Fairly complex portfolio problem - multiple dimensions, each asset can potentially yield a negative return, and it is highly unlikely that multiple assets will yield a negative return (knife-edge condition).
Introduction to the Pacific Whiting Fishery

- Complex structure of bycatch penalties.
- Only punished if bycatch limits or quota are excessive for a given species/season combination.
- MS-CV sector divides each season into “pools”, penalty for exceeding bycatch “base rate” for your pool...
  - only takes effect if that bycatch species shuts down the pool prematurely.
  - takes the form of reduced participation options later in the season.
  - Fairly complex portfolio problem - multiple dimensions, each asset can potentially yield a negative return, and it is highly unlikely that multiple assets will yield a negative return (knife-edge condition).
- Bycatch mitigation strategies/penalties in other sectors are not public.
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota *ex ante*
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota *ex ante*
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota *ex ante*
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$

With convex avoidance costs and linear exposure reduction...

The social planner’s solution is characterized by equalized bycatch avoidance behavior across all vessels.

There is no late-season bycatch quota price that can equalize bycatch avoidance across heterogeneous vessels mid-season.

Mid-season avoidance is higher for those who experienced early season bycatch (potential demanders) than those who did not (potential suppliers).
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota \textit{ex ante}
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota \textit{ex ante}
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
- Heterogeneity arises endogenously in the model, based on early season realizations of bycatch.
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota \textit{ex ante}
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
- Heterogeneity arises endogenously in the model, based on early season realizations of bycatch.
- With convex avoidance costs and linear exposure reduction...
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota *ex ante*
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
- Heterogeneity arises endogenously in the model, based on early season realizations of bycatch.
- With convex avoidance costs and linear exposure reduction...
  - The social planner’s solution is characterized by equalized bycatch avoidance behavior across all vessels.
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota \textit{ex ante}
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
- Heterogeneity arises endogenously in the model, based on early season realizations of bycatch.
- With convex avoidance costs and linear exposure reduction...
  - The social planner’s solution is characterized by equalized bycatch avoidance behavior across all vessels.
  - There is no late-season bycatch quota price that can equalize bycatch avoidance across heterogeneous vessels mid-season.
Model Sketch: Strategic Avoidance

- $n$ risk-neutral vessels, each a net supplier or demander of bycatch quota \textit{ex ante}
- Target species provides a certain harvest/payoff, provided the availability of bycatch quota $B_{it}$
- $B_{it}$ is discrete, Bernoulli distributed with parameter $p_B$
- Vessels’ control costly bycatch avoidance, $e_{it}$, and $p_B$ is strictly decreasing in $e_{it}$
- Heterogeneity arises endogenously in the model, based on early season realizations of bycatch.
- With convex avoidance costs and linear exposure reduction...
  - The social planner’s solution is characterized by equalized bycatch avoidance behavior across all vessels.
  - There is no late-season bycatch quota price that can equalize bycatch avoidance across heterogeneous vessels mid-season.
  - Mid-season avoidance is higher for those who experienced early season bycatch (potential demanders) than those who did not (potential suppliers).
Application of the Holmstrom-Milgrom model
Model Sketch: Principal-Agent

- Application of the Holmstrom-Milgrom model
- Fisheries manager is the principal, the fleet is the agent.
Model Sketch: Principal-Agent

- Application of the Holmstrom-Milgrom model
- Fisheries manager is the principal, the fleet is the agent.
- Moral hazard problem: Fleet engages in $t$ periods of effort, and observes the stochastic outcome after each period. The agent can adjust bycatch avoidance effort based on outcomes (parallel: sales force)
Model Sketch: Principal-Agent

- Application of the Holmstrom-Milgrom model
- Fisheries manager is the principal, the fleet is the agent.
- Moral hazard problem: Fleet engages in \( t \) periods of effort, and observes the stochastic outcome after each period. The agent can adjust bycatch avoidance effort based on outcomes (parallel: sales force)
- Principal only observes (and penalizes) based on cumulative bycatch.
Model Sketch: Principal-Agent

- Application of the Holmstrom-Milgrom model
- Fisheries manager is the principal, the fleet is the agent.
- Moral hazard problem: Fleet engages in $t$ periods of effort, and observes the stochastic outcome after each period. The agent can adjust bycatch avoidance effort based on outcomes (parallel: sales force)
- Principal only observes (and penalizes) based on cumulative bycatch.
- The optimal solution is a linear compensation model
Model Sketch: Principal-Agent

- Application of the Holmstrom-Milgrom model
- Fisheries manager is the principal, the fleet is the agent.
- Moral hazard problem: Fleet engages in $t$ periods of effort, and observes the stochastic outcome after each period. The agent can adjust bycatch avoidance effort based on outcomes (parallel: sales force)
- Principal only observes (and penalizes) based on cumulative bycatch.
- The optimal solution is a linear compensation model
  - Intuition
Data

- CP: Observer data, 1999-2014
- MSCV: Observer data, 1999-2014 (observers on board MS, not CV)
- SS: Fish ticket data, 1999-2014; Observer data 2011-2014
Overall Bycatch Rates

Bycatch Rates for Salmon and Rockfish, CP Sector

Year
Bycatch Rate
Bycatch per unit effort: CP Sector

Distribution of log(Rockfish lbs per tow hour), CP Fleet

Pre−2011
Post−2011
Bycatch per unit effort: MSCV Sector

Distribution of log(Rockfish lbs per tow hour), MS−CV Fleet
Bycatch per unit effort: SS Sector

Distribution of log(non-Widow Rockfish lbs per tow hour), SS FI

---

Pre-2011
Post-2011
Night Fishing: Pre-September

Time of Gear Deployment: Pre-September

Density

Pre-2011
Post-2011

SS
MSCV
CP

Hour of Gear Deployment

(0, 5, 10, 15, 20, 25)

(0.00, 0.04, 0.08, 0.12)
Night Fishing: Post-September

Time of Gear Deployment: Post–September

- Pre–2011
- Post–2011

- SS
- MS–CV
- CP

Density

Hour of Gear Deployment
Move-on Behavior

\[
\log(\text{Distance Moved}_{i,t}) = \beta_0 + \beta_1 \text{Whiting}_{i,t-1} + \beta_2 \text{Rockfish}_{i,t-1} \\
+ \beta_3 \text{Rockfish}_{i,t-1} \times \text{post-2011} \\
+ \text{Vessel FE} + \text{Year FE} + \varepsilon_{i,t}
\]
## Move-on Behavior

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>SS Sector</th>
<th>CP Sector</th>
<th>MS-CV Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log(Distance Moved)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hake$_{i,t-1}$</td>
<td>$-0.006^{***}$</td>
<td>$-0.020^{***}$</td>
<td>$-0.010^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1}$</td>
<td>$0.100^{***}$</td>
<td>$0.087^{***}$</td>
<td>$0.203^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
<td>(0.021)</td>
<td>(0.059)</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1} \times$ post-2011</td>
<td>$-0.082$</td>
<td>$0.639^{***}$</td>
<td>$0.391^{**}$</td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td>(0.187)</td>
<td>(0.149)</td>
</tr>
<tr>
<td>Observations</td>
<td>19,783</td>
<td>18,680</td>
<td>2,103</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.037</td>
<td>0.060</td>
<td>0.235</td>
</tr>
</tbody>
</table>

*Note:* $^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
## Move-on Behavior

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>SS</th>
<th>CP</th>
<th>MS-CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Log(Distance Moved)} )</td>
<td>Sector</td>
<td>Sector</td>
<td>Sector</td>
</tr>
<tr>
<td>Hake(_{i,t-1} )</td>
<td>-0.006***</td>
<td>-0.020***</td>
<td>-0.010***</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Rockfish(_{i,t-1} )</td>
<td>0.100***</td>
<td>0.087***</td>
<td>0.203***</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
<td>(0.021)</td>
<td>(0.059)</td>
</tr>
<tr>
<td>Rockfish(_{i,t-1} \times ) post-2011</td>
<td>-0.082</td>
<td>0.639***</td>
<td>0.391**</td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td>(0.187)</td>
<td>(0.149)</td>
</tr>
<tr>
<td>Observations</td>
<td>19,783</td>
<td>18,680</td>
<td>2,103</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.037</td>
<td>0.060</td>
<td>0.235</td>
</tr>
</tbody>
</table>

*Note:* \( ^* p<0.1; ^{**} p<0.05; ^{***} p<0.01 \)
Duration_{i,t} = \beta_0 + \beta_1 \log(\text{Distance Moved}_{i,t}) + \beta_2 \text{Distance Moved}_{i,t} \times \text{post-2011} + \beta_3 \text{Whiting}_{i,t-1} + \beta_4 \text{Rockfish}_{i,t-1} + \beta_5 \text{Rockfish}_{i,t-1} \times \text{post-2011} + \text{Vessel FE} + \text{Year FE} + \varepsilon_{i,t}
# Test Towing

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>SS</th>
<th>CP</th>
<th>MS-CV</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Tow Duration (Minutes)</em></td>
<td><em>Sector</em></td>
<td><em>Sector</em></td>
<td><em>Sector</em></td>
</tr>
<tr>
<td>log(Distance Moved)</td>
<td>$-1.954^{**}$</td>
<td>$-9.472^{***}$</td>
<td>$-7.816^{***}$</td>
</tr>
<tr>
<td>log(Dist.) $\times$ post-2011</td>
<td>2.033</td>
<td>-4.520$^{***}$</td>
<td>7.53$^*$</td>
</tr>
<tr>
<td>Hake$_{i,t \rightarrow t-1}$</td>
<td>$-1.363$</td>
<td>0.288$^{***}$</td>
<td>$-0.317^{***}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t \rightarrow t-1}$</td>
<td>$-8.829$</td>
<td>$-1.289^{***}$</td>
<td>14.491$^{**}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t \rightarrow t-1} \times$ post-2011</td>
<td>$-8.901$</td>
<td>$-36.523^{***}$</td>
<td>$-43.790^{**}$</td>
</tr>
<tr>
<td>Observations</td>
<td>19,769</td>
<td>18,572</td>
<td>2,103</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.237</td>
<td>0.313</td>
<td>0.192</td>
</tr>
</tbody>
</table>

*Note:* $^*$p$<=$0.1; $^{**}$p$<=$0.05; $^{***}$p$<=$0.01
## Test Towing

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>SS Sector</th>
<th>CP Sector</th>
<th>MS-CV Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tow Duration (Minutes)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(Distance Moved)</td>
<td>$-1.954^{**}$</td>
<td>$-9.472^{***}$</td>
<td>$-7.816^{***}$</td>
</tr>
<tr>
<td>log(Dist.) $\times$ post-2011</td>
<td>0.033</td>
<td>$-4.520^{***}$</td>
<td>7.53$^*$</td>
</tr>
<tr>
<td>Hake$_{i,t-1}$</td>
<td>$-1.363$</td>
<td>0.288$^{***}$</td>
<td>$-0.317^{***}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1}$</td>
<td>$-8.829$</td>
<td>$-1.289^{***}$</td>
<td>14.491$^{**}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1}$ $\times$ post-2011</td>
<td>$-8.901$</td>
<td>$-36.523^{***}$</td>
<td>$-43.790^{**}$</td>
</tr>
<tr>
<td>Observations</td>
<td>19,769</td>
<td>18,572</td>
<td>2,103</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.237</td>
<td>0.313</td>
<td>0.192</td>
</tr>
</tbody>
</table>

*Note:* $^*p<0.1; ^{**}p<0.05; ^{***}p<0.01$
## Test Towing

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>SS</th>
<th>CP</th>
<th>MS-CV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tow Duration (Minutes)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(Distance Moved)</td>
<td>$-1.954^{**}$</td>
<td>$-9.472^{***}$</td>
<td>$-7.816^{***}$</td>
</tr>
<tr>
<td>log(Dist.) $\times$ post-2011</td>
<td>2.033</td>
<td>$-4.520^{***}$</td>
<td>7.53$^*$</td>
</tr>
<tr>
<td>Hake$_{i,t-1}$</td>
<td>$-1.363$</td>
<td>0.288$^{***}$</td>
<td>$-0.317^{***}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1}$</td>
<td>$-8.829$</td>
<td>$-1.289^{***}$</td>
<td>14.491$^{**}$</td>
</tr>
<tr>
<td>Rockfish$_{i,t-1} \times$ post-2011</td>
<td>$-8.901$</td>
<td>$-36.523^{***}$</td>
<td>$-43.790^{**}$</td>
</tr>
<tr>
<td>Observations</td>
<td>19,769</td>
<td>18,572</td>
<td>2,103</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.237</td>
<td>0.313</td>
<td>0.192</td>
</tr>
</tbody>
</table>

*Note:*

$^*$ $p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Conclusion

- Evidence of reduced bycatch per unit effort under cooperative management for at-sea sectors.
Conclusion

- Evidence of reduced bycatch per unit effort under cooperative management for at-sea sectors.
- Evidence of increased bycatch avoidance from at-sea sectors after management change.
Conclusion

- Evidence of reduced bycatch per unit effort under cooperative management for at-sea sectors.
- Evidence of increased bycatch avoidance from at-sea sectors after management change.
  - The MS-CV sector decreased night-fishing significantly, although there is no change in the timing of tows for the CP fleet.

- One metric ton of rockfish is associated with 89% and 48% increases in distance moved for the CP and MS-CV sectors, respectively.

- Effect sizes for tow duration are relatively small except for the estimated effect of tow duration after a rockfish encounter. One metric ton of rockfish is associated with 37 and 44 minute decreases in tow duration on the following tow for the CP and MS-CV sectors, respectively.

- No significant evidence from the shoreside sector, although this may be a limitation of the data or the statistical model.
Conclusion

- Evidence of reduced bycatch per unit effort under cooperative management for at-sea sectors.
- Evidence of increased bycatch avoidance from at-sea sectors after management change.
  - The MS-CV sector decreased night-fishing significantly, although there is no change in the timing of tows for the CP fleet.
  - One metric ton of rockfish is associated with 89% and 48% increases in distance moved for the CP and MS-CV sectors, respectively.
Conclusion

- Evidence of reduced bycatch per unit effort under cooperative management for at-sea sectors.
- Evidence of increased bycatch avoidance from at-sea sectors after management change.
  - The MS-CV sector decreased night-fishing significantly, although there is no change in the timing of tows for the CP fleet.
  - One metric ton of rockfish is associated with 89% and 48% increases in distance moved for the CP and MS-CV sectors, respectively.
  - Effect sizes for tow duration are relatively small except for the estimated effect of tow duration after a rockfish encounter. One metric ton of rockfish is associated with 37 and 44 minute decreases in tow duration on the following tow for the CP and MS-CV sectors, respectively.
- No significant evidence from the shoreside sector, although this may be a limitation of the data or the statistical model.