Fishermen's location choice under spatio-temporal update of expectations

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RESEARCH QUESTION:
How fishermen form beliefs about the productivity of fishing grounds that drive their harvest location choices?

- What is the role of prior beliefs (i.e. expectations) in the decision with respect to location choice?
- How are the at-sea day-to-day locations adjusted based on signals obtained through harvest activity?

SPECIFIC ASPECTS OF COMMERCIAL FISHERY INCORPORATED IN THE MODEL

- Varying sites productivity (spatial and temporal, e.g. fish migratory patterns, seasonality, species composition, past exploitation patterns)
- Common vs. private knowledge about sites productivity
- True site productivity vs. individual expectation
- Heterogeneity of fleet (e.g. risk preferences in exploration vs. exploitation)
- Use of experience to update in space and time (correlation structure)

GOAL: To develop a method to derive empirically informed parameters used in models like ABM focusing on location choices
Each decision making unit (DMU) has a harvest location choice set represented by spatial rectangles (discrete choice, mutually exclusive, exhaustive and finite number)

DMU $n (n \in N)$ is utility maximizer when making choice $i$ at time $t (t \in T)$ compared to alternative choices $j (j \in J)$ based on expected attributes for each alternative ($x_{njt}$):

$$U_{njt} = V_{njt}(x_{njt}) + \varepsilon_{njt}$$
$$P_{nit} = P(U_{nit} > U_{njt} \forall j \neq i)$$

Decision is made under uncertainty and motivated by individual expectations:

$$\neg \Box (x_{njt} \neq x_{mjt}) \text{ for } n, m \in N$$

Utility is realized only after a decision has been made

Each decision/action updates the future expectations
Prior Expectations

- \( R = f(z_k, u, \pi) \) - revenue on site, function of variable inputs \( k \ (k \in K) \), individual efficiency \( u \) and environmental productivity \( \pi \):

\[
\ln(R_{njt}) = \alpha_0 + \sum_{k \in K} \alpha_k \ln(z_k) + u_n + \pi_{jt} + \epsilon_{njt}
\]

- Fishermen have prior beliefs based on past experiences (common knowledge) that vary over space and time

- Empirically: (1) Regress the logged revenue equation with a fixed effects on lagged data for the whole fleet, and (2) create an expectation plain based on \( \pi_{jt} \) results using spatio-temporal kriging
\( \pi_{jt} \) is not certain: \( E(\pi_{jt}) \sim N(\mu_{jt}, \sigma_{jt}^2) \)

Sites harvested frequently are considered to have lower variance in expected productivity than sites rarely harvested, i.e. non-fished sites present higher uncertainty for fishermen

Variance in expected productivity is used as proxy for risk attitude in the location choice model
Updating Individual Expectations

➢ Krige output as initial values for individual updating process → Bayesian priors

➢ Individual realized productivity at the site (signal): \( S_{njt} = \pi_{jt} + e_{njt} \) with \( \sigma_s^2 < \sigma_0^2 \)

➢ Bayes normal updating applied iteratively

\[
E(\pi_{njt} | S_{njt}) \sim N \left( \frac{S_{njt} \sigma_s^2 + \mu_{njt} \sigma_s^2}{\sigma_{njt}^2 + \sigma_s^2}, \frac{\sigma_{njt}^2 \sigma_s^2}{\sigma_{njt}^2 + \sigma_s^2} \right)
\]

➢ Good signals (i.e. \( S_{njt} > \mu_{njt} \)) increase future \( E(\pi_{njt}) \) with weight determined by signal noise; posterior variance decreases by \( \sigma_s^2 / (\sigma_{njt}^2 + \sigma_s^2) \)

➢ Note: while priors are common knowledge, signals are private knowledge
Assuming that environmental productivity is correlated in space and time, but that reliability of information decays in space and time $\rightarrow$ spatio-temporal updating

$$
E(\pi_{njt} | S_{njt}) \sim N(\mu_{n'jt} + (S_{njt} - \mu_{njt}) \frac{\text{COV}\{\pi_{njt}, \pi_{nj't'}\}}{\sigma_{njt}^2 + \sigma_s^2}),
$$

$$
\sigma_{nj't'}^2 - \frac{\text{COV}\{\pi_{njt}, \pi_{nj't'}\}}{\sigma_{njt}^2 + \sigma_s^2}
$$

$$
\text{COV}\{\pi_{njt}, \pi_{nj't'}\} = \sigma_{njt}\sigma_{nj't'}\rho_{sp}(|d_{jj'}|; \phi_{sp})\rho_{tp}(|d_{tt'}|; \phi_{tp})
$$

- $\rho_{sp}$ & $\rho_{tp}$ - spatial and temporal correlation functions of distance and parameters $\phi \rightarrow \phi_{sp}$ & $\phi_{tp}$ needs to be determined
- Separable correlation structure
Knowledge Decay over Time and Space

- Simulation of a two-dimensional grid with varying $\phi_{sp}$ & $\phi_{tp}$ based on Halton draws and generating dataset of updated expectations regarding environmental productivity ($\pi_{it}$)

- Mixed logit estimation for each simulated dataset:

$$P_{nit} = \int \left( \frac{e^{\beta'x_{nit}}}{\sum_j e^{\beta'x_{nit}}} \right) f(\beta) d\beta \text{ with } f(\beta) = f(dist_{nit}, \pi_{nit}, \text{var}(\pi_{nit}))$$

- Model comparison via Akaike Information Criteria
Polish logbook data for demersal trawl from 2011 & 2012 (39 DMUs)

- 99 location to choose from in the southern Baltic Sea
- 2011: 3,383 At-sea day-choices on 1,539 trips in 84 locations
- 2012: 2,811 At-sea day-choices: signals in the updating process
  - 1,111 At-sea day-choice: 1) stay or 2) change which are used in the mixed logit model
Fixed effect regression based on trawling hours

$$\ln(R_{njt}) = \alpha_0 + \sum_{k \in K} \alpha_k \ln(z_k) + u_n + \pi_{jt} + \varepsilon_{njt}$$

Priors 2011 (expected environmental productivity)

a) March 1, 2011

b) June 1, 2011

c) September 1, 2011

d) December 1, 2011
Mixed logit estimation (1)

- 3,196 iterations

- 1,111 choices for 99 locations, i.e. 109,989 alternatives

- Mixed logit with lowest AIC for varying $\phi_{sp}$ & $\phi_{tp}$, with $\sigma_s^2 = 0.5 \sigma_{ntj}^2$

- Global minimum: $\phi_{sp} = 0.0250$ & $\phi_{tp} = 0.1125$

- Correlation equal to 0.5 with spatial separation of 28 km or temporal separation of 6 days.

AIC contour plot
Results for the best fit mixed logit

- Predicted probability higher for observed chosen areas than for alternatives
- 750 out of 1,111 choices are correctly predicted (67.5 %), 99.7% correctly rejected.
- Additionally, 197 predictions to neighbor area (17.7%); over 85% observations predicted correctly to nearest neighbor.

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<th>Variable</th>
<th>Coefficient</th>
<th>robust SE</th>
<th>p-value</th>
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<tr>
<td>Distance added [km]</td>
<td>-0.014</td>
<td>0.002</td>
<td>0.000</td>
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<tr>
<td>Expected productivity$^1$</td>
<td>0.818</td>
<td>0.146</td>
<td>0.000</td>
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<tr>
<td>Expected productivity variance</td>
<td>-10.829</td>
<td>0.294</td>
<td>0.000</td>
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<td>SD: Expected productivity variance</td>
<td>1.759</td>
<td>0.343</td>
<td>0.000</td>
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Akaike Information Criteria - AIC=3236.237

H0: no random effects - Wald test $\chi^2 = 26.285$, $p = 0.000$
Moving between fishing grounds is not a random search process, but rational choice based on prior expectations & economic incentives.

Environmental productivity expectations are continuously updated with signal strength decaying over space and time.

Polish fishermen are risk-averse considering their at-sea location choice (‘old habits die hard’) although the model allows risk-heterogeneity.

Calibration method can be used to inform, e.g. agent-based models, on relevant parameters.
Other aspects to consider/implement

- Alternative sources of updating (e.g. communication)
- Competition on site (depends how big are considered sites)
- Exploitation impact on site productivity
- Limited choice set (spatial closures)
Figure 1: Density plot of the estimated environmental productivity factor $\pi_{jt}$. 
Fixed effect regression based on trawling hours

\[
\ln(R_{njt}) = \alpha_0 + \sum_{k \in K} \alpha_k \ln(z_k) + u_n + \pi_{jt} + \varepsilon_{njt}
\]

Variogram

\[
\text{cov}_{\text{priors}}(|d_{jj'}|, |d_{tt'}|) = k \text{cov}_{sp}(|d_{jj'}|) \text{cov}_{tp}(|d_{tt'}|) + \text{cov}_{sp}(|d_{jj'}|) + \text{cov}_{tp}(|d_{tt'}|)
\]

Space: psill=1, Exp, range=8, nugget=0.5
Time: psill=1, Exp, range=3, nugget=2
k=3
Figure 5: Distribution of random coefficients on expectation variance - risk attitude heterogeneity.
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Motivation

TEMPLATE - KEEP