Three species and three agents on a common ground

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MESSAGE

Model

- Dynamic model with three interacting species and three agents on a common ground.
- Herring, mackerel, blue whiting.
- Norway, UK and Iceland
- Biological interaction between species and strategic interaction between agents.
- Five possible cases.

Possibilities

- Co-operation
- Full competition
- Three coalitions:
  - (Norway&Iceland) + UK
  - (Norway&UK) + Iceland
  - (Iceland&UK) + Norway

Assumptions

- Whenever agents cooperate, they aim at maximizing long-term discounted revenue, taking stock dynamics into account.
- Whenever agents act as singletons, they only maximize short-term revenue (myopic behavior).

Notation/Dynamics

- X is escapement, S is initial stock, H is harvest
- $X_{i,t} = S_{i,t} - \sum_l H_{i,t,l}$
- $S_{i,t+1} = X_{i,t} + r_i X_{i,t} \left(1 - \frac{\sum X_{j,t}}{K}\right)$

Harvest function

- Within one period
- Total harvest: $H = \frac{S \cdot E}{E+1}$
- Total effort: $E = \frac{S-X}{X}$
- Individual effort: $E_{i,t,l} = \frac{h_{i,t,l}}{S_{i,t} - \sum_k h_{i,t,k}}$

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Optimization model

- Cooperatice case

$$Max \sum_i \sum_l \sum_t \delta^t \left(p_{i,l} h_{i,t,l} - \beta_{i,l} E_{i,t,l}\right)$$

Subject to $E_{i,t,l} = \frac{h_{i,t,l}}{S_{i,a} - \sum_l h_{i,t,l}}$

and the dynamic constraints for all species and all years.

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Optimization model

- With $T = 50$ we have some 900 equations and 1350 variables.
- Without discounting the system tends to move to a steady state by itself.
- KNITRO solver in a GAMS environment using DNLP (Nonlinear programming with discontinuous derivatives)

Optimization model

- Competitive case; all are myopic

- $h_{i,t,l} = max\left[0, \left(S_{i,t} - \sum_{k\neq l} h_{i,t,k}\right) - \sqrt{\frac{\beta_{i,l}\left(S_{i,t} - \sum_{k\neq l} h_{i,t,k}\right)}{p_{i,l}}}\right]$

- $E_{i,t,l} = \sqrt{\frac{p_{i,l} S_{i,t}\left(1 + \sum_{k\neq l} E_{i,t,k}\right)}{\beta_{i,l}}} - \left(1 + \sum_{k\neq l} E_{i,t,k}\right)$

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Optimization model

- 1 and 2 cooperate, 3 is singleton

$$Max \sum_{i} \sum_{l=1}^{2} \sum_{t} \delta^{t} \left(p_{i,l} h_{i,t,l} - \beta_{i,l} E_{i,t,l} \right)$$

s.t.

$$h_{i,t,3} = max \left[0, \left(S_{i,t} - \sum_{k=1,2} h_{i,t,k} \right) - \sqrt{\frac{\beta_{i,l} \left(S_{i,t} - \sum_{k=1,2} h_{i,t,k} \right)}{p_{i,l}}} \right]$$

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Some definitions

- **Coalition structure**: Partition of the players into disjoint and exhaustive coalitions.
- **Embedded coalition structure**: A pair consisting of a coalition and a coalition structure.

Some definitions

- **Internal stability** of an embedded coalition: None of the members have incentives to withdraw
- **External stability**: No other coalition has incentives to join.

Results

- Undiscounted steady state revenue:

Country	NO	UK	ICE	Total
Coal.struc				
Coop	478	12	-11	479
Ice+UK	36	10	0.2	47
Ice+NO	42	7	0.8	50
NO+UK	143	1	0.3	145
Comp.	40	7	1	48

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Results

- Stability of embedded coalitions

Embedded coalition		Intern. Stab.	Extern.stab
(NO,UK,ICE)	(NO,ICE,UK)	no	yes
(UK,ICE)	(UK,ICE),NO	no	no
NO	(UK,ICE),NO	yes	yes
(NO,ICE)	(NO,ICE),UK	no	no
UK	(NO,ICE),UK	yes	no
(NO,UK)	(NO,UK),ICE	no	yes
ICE	(NO,UK),ICE	yes	no
NO	NO,UK,ICE	yes	yes
UK	NO,UK,ICE	yes	no
ICE	NO,UK,ICE	yes	no

Results: Stock and harvest

	Species	NO	UK	ICE	Stock
COOP	Herring	0	0	354	2 854
	Mackerel	2 935	0	0	15 546
	Blue W	0	479	0	1 979
COMP	Herring	1 046	101	173	6 603
	Mackerel	654	288	0	3 231
	Blue W	0	201	205	1 126
ACTUAL (2014)	Herring	263	4	59	5 496
	Mackerel	278	288	173	3 998
	Blue W	399	27	183	3 867

Conclusions

- The most likely outcome is full competition where everybody behave myopically.
- This is also the the case which is most similar to real world observations.
- Cooperation and long-term maximization would increase total net revenue ten times.

Conclusions

- For this to happen, Norway would have to give the other two heavy side payments.
- This is not realistic, but the same effect could be achieved through quota negotiations involving other species.

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