



Game Theory and Fish Wars: The North Atlantic Mackerel Crisis

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1. Research questions

- Until 2009: an agreement between EU, Norway and Faroe Islands on a total quota for fishing mackerel in the North Atlantic Sea
- From 2008: Iceland started to fishing mackerel in the area
- From 2009 and onwards: EU, Norway, Iceland and Faroe Islands could not reach a agreement on a total quota.



1. Research questions

- 2010: EU and Norway reached a bilateral agreement
- From 2010 and onwards: Iceland and Faroe Islands increased the harvest of mackerel.
- 2014: EU, Norway and Faroe Islands entered and agreement about a total quota. Iceland did not participate in the agreement.



1. Research questions

- These facts to two research questions:
 - a. Can we explain why Iceland and Faroe Islands decide to increase harvest while Norway and EU entered a bilateral agreement in 2010?
 - b. Can we explain why no bargaining agreement was reached in the period 2010-2014 between EU, Norway, Iceland and Faroe Islands?

Question a: Non-cooperative game theory is used.

Question b: Cooperative game theory is used.



2. Models

- Normal in fisheries economics: The actors maximize profits (revenues minus costs) subject to a resource restriction stating that the change in stock size is equal to the natural growth minus the harvest.
- Within this model strategic interaction can arise due to two facts:
 - a. A negatively sloped demand curve
 - b. The stock of fish (the resource restriction)



2. Models

- I investigate three empirical models in the paper:
 - A. A pure price game
 - B. A pure stock game
 - C. A mixed price and stock game

Model A: Only strategic interaction due to a negatively sloped demand function.

Model B: Only strategic interaction due to the stock size.

Model C: Strategic interaction due to both the demand function and stock size.



3. Solution concepts

- I investigate the mackerel crisis using very simple solution concepts.
- Non-cooperative games: Nash equilibrium and dominant strategies.
- Nash equilibrium: Each player have no incentive to deviate from a strategy given the strategy for other players.
- Dominant strategies: A strategy is optimal for a player given all other possible strategies from other players.



3. Solution concepts

- Cooperative game theory: Core and Shapley value.
- Core: Maximum payoff a player can get from forming coalitions
- Shapley value: Each player get the average value of the marginal contribution to coalitions.
- Criteria used in the paper: The Shapley value shall be within the core.



4. Empirical model

- Pure price game and combined price and stock game: a negatively sloped demand function given as:

$$P = a - bh_{EU} - bh_{No} - bh_{IC}$$

All three games: A cost function given as:

$$C_i(h_i) = c_i h_i^2$$



4. Empirical model

- For the pure stock game and the combined price and stock game a growth function given as:

$$F(x) = rx(1 - x/K)$$

- In all models: Iceland and Faroe Islands is treated as one player because off lack of data for Faroe Islands



5. Payoffs

- In all three models: harvest is strategic variable.
- In principle: payoffs shall be found by maximizing profit subject to a resource restriction.
- Imply that five non-linear equations with five unknowns shall be solved.
- Can be done numerically, but I use simpler procedures.



5. Payoffs

- In pure price game: Use actual harvest under non- cooperative and cooperative behavior.
- In pure stock game and combined price and stock game I use that:

$$\Delta x_t = F(x_t) - h_{tEU} - h_{tNO} - h_{tIC}$$



5. Payoffs

- Period 0 (2010): we have h_0 and x_0 . Can be used to find x_1 .
- From x_1 $F(x_1)$ can be found. Now it is assumed that each player harvest $\frac{\Delta x_t}{x_t} > 0$ a constant share of the stock in each period. With this h_1 for each player can be found. Now x_2 can be found from the equation and from this $F(x_2)$ and h_2 . This procedure Δx_t continue until a steady-state is found.



5. Payoffs

- The harvest of each player in the steady-state equilibrium is the value of the strategic variable. This imply that we need information about harvest as a share of stock size for each player
- The payoff in the pure price game and combined price and stock game is:

$$\pi_i = (a - bh_{EU} - bh_{NO} - bh_{IC})h_i - c_i h_i^2$$



5. Payoffs

- Pure price game: actual harvest is used.
- Combined price and stock game: procedure using harvest as a share of the stock size is applied.
- Pure stock game:
$$\pi_i = ph_i - c_i h_i^2$$
- This procedure also use information about price as a share of the stock size



6. Data

- Select one fleet segment for each player: in order to avoid aggregation problems
 - A. EU: British purse seiners larger than 40 meter. Harvest 58% of the EU harvest of mackerel in the North Atlantic Sea.
 - B. Norway: Norwegian purse seiners larger than 40 meters. Harvest 73% of the Norwegian harvest.
 - C. All Icelandic pelagic trawlers. Harvest 98% of the Icelandic harvest



7. Empirical parameters and values

- Demand function used in the pure price game and combined price and stock game:
 - $a = 1.28$ mill EURO (12.48)
 - $b = -0.0003971$ mill EURO/1000 tons (-4.78)
 - $R^2 = 0.847$
 - $DW = 1.28$

Note that the demand function is flat compared to other studies

Price used in pure stock game:

$$P = 1.14 \text{ (mill. Euro/100 tons)}$$



7. Empirical parameters and values

- Cost parameter used in all three games

	EU	NO	IC
Ci (mill. Euro/1000 tons)	0.004927	0.006590	0.005197

- Note cost parameters is close to each other and low compared to other studies



7. Empirical parameters and values

- Growth function used in pure stock game and combined price and stock game:
 - $r = 0.47$ (1.44)
 - $K = 8266$ 1000 tons (0.99)
 - $R2 = 0.22$



7. Empirical parameters and values

- Actual harvest used in the pure price game:

	EU	NO	IC
C (1000 tons)	242	121	130
NC (1000 tons)	523	262	281

- Note: NC for EU and NO is calculated from C as a share of NC for Iceland
- Harvest under both C and NC is largest in EU
- For all players harvest is largest under NC.



7. Empirical parameters and values

- Harvest as a share of stock size used in pure stock game and combined price and stock game.

	EU	NO	IV
C (%)	5	2	3
NC (%)	13	6	7



8. Non-cooperative solution to the games

- In all three games: (NC, NC, NC,) is the Nash equilibrium.
- The result is robust to changes in all parameter values on +/- 50%.
- Thus, according to the models all three EU, Norway and Iceland shall act non-cooperative
- Thus, I cannot predict why EU and Norway acted cooperatively while Iceland acted cooperative from 2010



8. Non-cooperative solution to the games

- Intuition: The cost parameter is identical for the three players and with this they shall adopt the same strategy.
- The cost parameter is low so it is beneficially to select a large harvest (play non-cooperative).



8. Non-cooperative solution to the games

- For revenue the demand function is flat and with this an increase in harvests does not affect the price very much.
- In total: the cost effect and revenue effect explains why non-cooperative behavior is optimal for all three players.



9. Cooperative solution to the games

- In all three games: Core in a three player game is empty and Shapley value is outside the core.
- Same holds for all two player games.
- Both conclusions robust to changes in parameter values on +/- 50%.
- All players has an incentive not to enter a bargaining agreement
- Thus, we can explain why EU, Norway, Iceland and Faroe Islands did not reach an agreement between 2010-2014



9. Cooperative solution to the games

- Intuition: the same as with non-cooperative game.
- The cost parameter is low and the demand function is flat implying that increasing harvest by acting alone is not costly.



10. Alternative explanation

- Alternative to model for non-cooperative game: Depart from opportunity cost.
- With opportunity cost: lost revenue of harvesting other species when shifting to mackerel is a cost.
- EU and Norway: have a capacity limit so this cost is high.
- Iceland: Harvest of blue whiting decrease considerably. Lost revenue when shifting to mackerel is low and with this costs is low.



10. Alternative explanation

- High cost in EU and Norway: act cooperatively
- Low cost in Iceland: act non-cooperative.
- Thus: non-cooperative games in combination with opportunity cost can explain actual behavior



11. Conclusion

- We can conclude:
 - A. With opportunity cost we can explain why EU and Norway entered a bilateral agreement in 2010 while Iceland and Faroe Islands acted non-cooperative.
 - B. With harvest costs we can explain why EU, Norway, Iceland and Faroe Islands did not enter a bargaining agreement to the mackerel crisis.

