INTERNATIONAL FISHERIES AGREEMENTS: A GAME THEORETICAL APPROACH

PEDRO PINTASSILGO

Faculty of Economics
University of Algarve
Faro, Portugal

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Outline

1. International Fisheries Agreements
2. Game Theory
3. Stability and Success of International Fisheries Agreements
4. Recent Developments
5. Conclusion

1. International Fisheries Agreements

- The management of fish stocks shared by several countries is an important economic and political issue at the international level.
- The harvests of these stocks are highly important: about one third of world marine capture fishery harvests (Munro, Van Houtte, Willmann, 2004).
- Shared Fish Stocks:
  - Transboundary stocks (move between the EEZs of more than one country);
  - Straddling Fish Stocks (move between EEZs and the high seas);
  - Discrete High Seas Stocks (found only in the high seas).

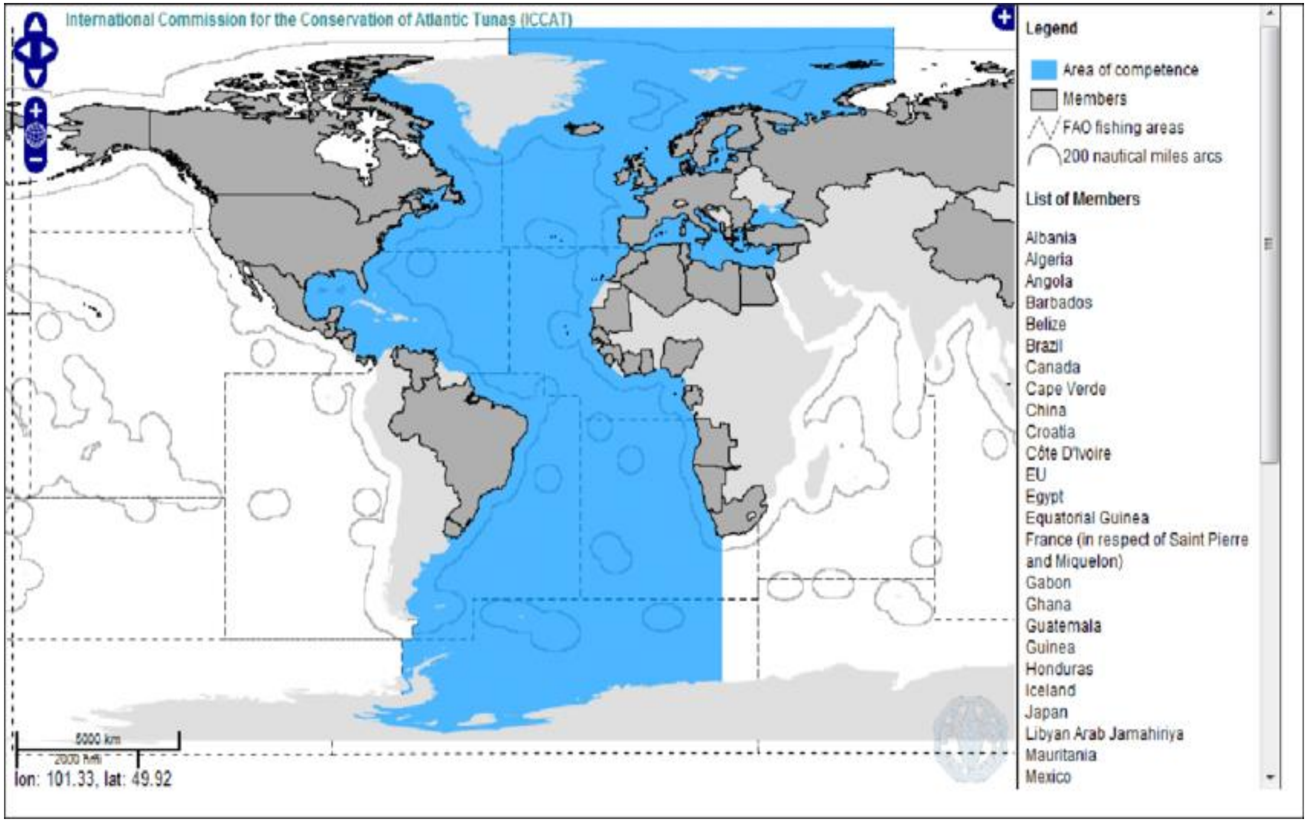
1. International Fisheries Agreements

- In the early 1980s, the internationally shared fish stocks issue was focused on transboundary fish stocks.
- Many straddling fish stocks were subject to heavy overexploitation in the decade following the 1982 UN Convention.
- Conflicts between countries emerged (e.g. the "Turbot War").
- This led to the UN Fish Stocks Conference (1993-1995) which brought forth the 1995 UN Fish Stocks Agreement.
- According to the Agreement, straddling fish stocks should be managed by Regional Fisheries Management Organizations (RFMOs).

1. International Fisheries Agreements

- RFMOs should have as members all coastal states and distant water fishing states claiming to have a "real interest" in the relevant fish stocks (UN, 1995, Article 8).
- The members of an RFMO should cooperate to conserve and manage the straddling stocks.
- Examples:
  - North-East Atlantic Fisheries Commission (NEAFC)
  - International Commission for the Conservation of Atlantic Tunas (ICCAT)

1. International Fisheries Agreements



Source: FAO (2018)

1. International Fisheries Agreements

- Some challenges to cooperative management under RFMOs:
  - Free riding incentives of member countries;
  - Prospective New Members:
    - "States having a real interest in the fisheries concerned may become members of such organization or participants in such arrangement." (UN, 1995: article 8);
  - Unregulated fishing: Non-members acting non-cooperatively.

1. International Fisheries Agreements

- Questions that emerge on International Fisheries Agreements:
  - How to distribute the fish stock among the members in a fair way?
  - Which countries have incentive to join/leave the RFMO?
  - How stable and successful will be an RFMO?
- Game theory helps to answer these questions.

2. Game Theory

- Game Theory: Studies the behavior of decision makers ("players") whose decisions affect each other (Aumann and Hart, 1992).
- Game: formal representation (mathematical model) of the strategic interaction between players.
- The genesis of Game Theory is the work by John von Neumann and Oskar Morgenstern (1944): Theory of Games and Economic Behavior.
- Considered as a branch of Mathematics, Game Theory gained special importance in Economics.

2. Game Theory

- The Nobel Prize in Economics was attributed several times to Game Theorists:
  - John Harsanyi, John Nash and Reinhard Selten (1994);
  - Robert Aumann and Thomas Schelling (2005);
  - Leonid Hurwicz, Eric Maskin and Roger Myerson (2007);
  - Alvin Roth and Lloyd Shapley (2012);
  - Jean Tirole (2014).

2. Game Theory

- The first application of Game Theory to fisheries is due to Munro (1979).
- Munro used a 2-player game to address the cooperative management of transboundary stocks in the context of the UN Convention on the Law of the Sea.
- Kaitala and Lindroos (1998) introduced coalition games in fisheries in the form of characteristic function games.
- These are cooperative games focused on how to share the surplus from cooperation.
- Several sharing rules are used: Nash bargaining solution; Shapley Value; Nucleolus, etc.

2. Game Theory

- According to Bloch (2003), there are three basic questions on coalition formation:
  1) Which coalitions will form ?
  2) How will the coalitional worth be divided among coalition members ?
  3) How does the presence of other coalitions affect the incentives to cooperate ?
- Characteristic function games only address question 2).
- Pintassilgo (2003) introduced partition function games (Non-cooperative games of coalition formation) to fisheries management.
- Partition function games became a standard tool to address the formation and stability of IFAs.

2. Game Theory

- Concepts:

A Coalition Structure $C = \{S_1, S_2, ..., S_z\}$ is a partition of the set of players $N = \{1, 2, ..., n\}$.

The Partition Function $\Pi(S_k; C)$ yields the payoff of coalition S_k , which is an element of the coalition structure C .

- Partition function: assigns a value to each coalition, which depends on the entire coalition structure.
- Partition function is a generalisation of the characteristic function.
- Besides fisheries, partition function games have been applied o a wide range of phenomena – e.g. the formation of international environmental agreements, cartels, custom unions.

3. Stability and Success of IFAs

- We will now address the stability and success of IFAs through a partition function game based on:

Pintassilgo, P., L. Kronbak, M. Lindroos (2015). International Fisheries Agreements: A Game Theoretical Approach. *Environmental & Resource Economics*, Vol. 62, No 4, pp. 689-709.

3.1 The Bioeconomic Model

- Classical Gordon-Schaefer bioeconomic model.

- Fish stock dynamics:

$$\frac{dX}{dt} = G(X) - \sum_{i=1}^{n} H_i$$

$$G(X) = rX\left(1 - \frac{X}{k}\right)$$

$$H_i = qE_iX$$

X - fish stock biomass;

$G(X)$ - stock growth function;

H_i - harvest of player i;

E_i - fishing effort of player i.

r - intrinsic growth rate

k - the carrying capacity

- Steady-state relation between fishing effort and stock:

$$X = \frac{k}{r}\left(r - q\sum_{i=1}^{n} E_i\right)$$

- Profit of State i:

$$\Pi_i = pH_i - cE_i = pqE_i\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{n} E_\ell\right)\right) - cE_i$$

p - is the price for fish;

c_i - cost per unit of effort of state i.

3.2 Coalition Formation Model

- Two-Stage Single Coalition and Open-Membership (d'Aspremont et al. 1983)
  - First stage: players chose membership (RFMO versus no RFMO);
  - Second stage: players chose fishing efforts.
- Game solved by backward induction.

3.2 Coalition Formation Model

Stage 1: Membership

Stage 2: Fishing Effort Decision

3.2 Coalition Formation Model

Stage 1: Membership

Coalition Structure:

$$C = \{S, 1_{n-m}\}$$

S : Coalition of size m;
1_{n-m}: n-m singletons.

Stage 2: Fishing Effort Decision

3.2 Coalition Formation Model

Stage 1: Membership

Coalition Structure:

$$C = \{S, 1_{n-m}\}$$

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Stage 2: Fishing Effort Decision

Coalition Members: $\max_{E_S} . \Pi_S = \sum_{i \in S} \Pi_i (E_S, E_{-S})$

Singletons: $\max_{E_j} . \Pi_j (E_j, E_{-j}) \; \forall \; j \notin S$

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Coalition Members: $$\max_{E_S}.\ \Pi_S = \sum_{i \in S} \Pi_i\left(E_S, E_{-S}\right)$$

$$\Rightarrow E^*(S) \Rightarrow \Pi^*(S)$$

Singletons: $$\max_{E_j}.\ \Pi_j\left(E_j, E_{-j}\right)\ \forall\ j \notin S$$

3.2 Coalition Formation Model

Stage 1: Membership

$$C = \{S, 1_{n-m}\}$$

internal stability: $\Pi_i^*(S) \geq \Pi_i^*(S \setminus \{i\}) \ \forall\, i \in S$

external stability: $\Pi_j^*(S) > \Pi_j^*(S \cup \{j\}) \ \forall\, j \notin S$

Stage 2: Fishing Effort Decision

Coalition Members: $\max\limits_{E_S} . \Pi_S = \sum\limits_{i \in S} \Pi_i(E_S, E_{-S})$

$$\Rightarrow E^*(S) \quad \Rightarrow \quad \Pi^*(S)$$

Singletons: $\max\limits_{E_j} . \Pi_j(E_j, E_{-j}) \ \forall\, j \notin S$

3.2 Coalition Formation Model

- What sharing rule should be used ?
- Almost Ideal Sharing Scheme (AISS) - Eyckmans and Finus (2009). Allocates to each coalition member its free-rider payoff plus some share of the coalition surplus (coalition payoff minus the sum of free-rider payoffs).

$$\Pi_i(S) = \Pi_i(S \setminus \{i\}) + \lambda_i(S)\Delta(S)$$

Free rider payoff

Coalition Surplus

Share

Where:

$$\Delta(S) = \Pi(S) - \sum_{i \in S} \Pi_i(S \setminus \{i\})$$

Coalition payoff

Sum of free rider payoffs

3.2 Coalition Formation Model

- When the coalition surplus is non-negative the coalition is Internally Stable under the AISS.
- In our game the Internal Stability Condition depends only on:

$n - number\ of\ fishing\ states$

$m - number\ of\ coalition\ members$

$b_i = \dfrac{c_i}{pqk} \in [0,1],\ i \in N$ - inverse efficiency parameter

3.3 Simulation Method

- Assumption:

$$b_i \sim U(0,1), \quad \forall i \in \{1,\ldots,n\}$$

- Monte Carlo simulation method: 50,000 simulations of the b vector, for each combination of n and m to compute:
  - Stability likelihood (probability);
  - Two Welfare Indexes:
    - Social Gain Index (SGI);
    - Closing the Gap Index (CGI).

3.3. Simulation Method

- Social Gain Index (SGI): measures of the potential gains from full cooperation

Gains from Cooperation

$$SGI\left(b,n\right)=\frac{Aggregate\ Payoff_{Grand\ Coalition}-Aggregate\ Payoff_{Full\ Non\text{-}cooperation}}{Aggregate\ Payoff_{Grand\ Coalition}}$$

- Closing the Gap Index (SGI): measures how much the stable equilibria closes the gap between full and no cooperation

Effective Gains in the Equilibrium

$$SGI\left(b,n\right)=\frac{Aggregate\ Payoff_{Stable\ Coalition}-Aggregate\ Payoff_{Full\ Non\text{-}cooperation}}{Aggregate\ Payoff_{Grand\ Coalition}-Aggregate\ Payoff_{Full\ Non\text{-}cooperation}}$$

Gains from Cooperation

3.4 Simulation Results

- Internal Stability Likelihood

Number of Coalition Members (*m*)	Number of Players (*n*): 2	3	4	5	6	7	8	9	10
n	1	0.777	0.345	0.103	0.022	0.004	0.001	0	0
n-1	1	0.826	0.417	0.147	0.037	0.007	0.001	0	0
n-2	–	1	0.646	0.273	0.080	0.019	0.004	0.001	0
n-3	–	–	1	0.538	0.195	0.054	0.011	0.002	0.001
n-4	–	–	–	1	0.466	0.150	0.037	0.007	0.002
n-5	–	–	–	–	1	0.409	0.120	0.026	0.005
n-6	–	–	–	–	–	1	0.367	0.098	0.021
n-7	–	–	–	–	–	–	1	0.333	0.081
n-8	–	–	–	–	–	–	–	1	0.308
n-9	–	–	–	–	–	–	–	–	1

3.4 Simulation Results

- Stability Likelihood – Base Case

Number of Coalition Members (*m*)		Number of Players (*n*) 2	3	4	5	6	7	8	9	10
	n	1	0.777	0.345	0.103	0.022	0.004	0.001	0	0
	n-1	0	0.127	0.149	0.074	0.023	0.004	0.001	0	0
	n-2	–	0.028	0.148	0.101	0.036	0.010	0.002	0	0
	n-3	–	–	0.036	0.126	0.071	0.023	0.005	0.001	0
	n-4	–	–	–	0.035	0.112	0.053	0.015	0.003	0.001
	n-5	–	–	–	–	0.030	0.101	0.040	0.011	0.002
	n-6	–	–	–	–	–	0.026	0.090	0.031	0.007
	n-7	–	–	–	–	–	–	0.025	0.082	0.025
	n-8	–	–	–	–	–	–	–	0.020	0.076
	n-9	–	–	–	–	–	–	–	–	0.017
$\overline{\text{SGI}}(n)$		14.8	25.5	33.6	39.9	45.1	49.4	53.0	56.1	58.8
$\overline{\text{CGI}}(n)$		100	87.2	55.4	30.4	16.3	9.3	5.9	4.0	2.8

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3.4 Simulation Results

- Success Indexes Estimates – Asymmetry Effect

Range of b_i´s		Number of Players								
		2	3	4	5	6	7	8	9	10
		Asymmetry Effect								
0.2	$\overline{SGI}(n)$	11.1	25.0	36.0	44.4	51.0	56.3	60.5	64.0	66.9
	$\overline{CGI}(n)$	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[0.1;0.3]	$\overline{SGI}(n)$	16.1	29.9	39.2	45.6	50.1	53.5	56.2	58.7	60.8
	$\overline{CGI}(n)$	100.0	43.8	17.3	9.9	6.6	4.7	3.5	2.7	2.1
[0;0.4]	$\overline{SGI}(n)$	17.3	28.2	35.5	41.2	45.9	49.9	53.3	56.3	59.0
	$\overline{CGI}(n)$	100.0	76.7	42.7	23.3	13.5	8.4	5.5	3.9	2.8

3.4 Simulation Results

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3.4 Simulation Results

- Success Indexes Estimates – Efficiency Effect

Range of b_i´s		Number of Players								
		2	3	4	5	6	7	8	9	10
		Efficiency Effect								
[0;0.2]	$\overline{SGI}(n)$	15.8	29.7	39.4	46.2	50.9	54.4	57.2	59.5	61.6
	$\overline{CGI}(n)$	100	38.9	15.2	8.5	5.7	4.1	3.1	2.4	1.9
[0.2;0.4]	$\overline{SGI}(n)$	16.4	29.9	38.8	44.8	49.0	52.4	55.3	57.9	60.2
	$\overline{CGI}(n)$	100.0	50.2	19.8	11.4	7.6	5.4	4.0	3.0	2.3
[0.4;0.6]	$\overline{SGI}(n)$	17.2	29.3	36.9	42.3	46.8	50.6	53.8	56.7	59.2
	$\overline{CGI}(n)$	100	67.8	31.6	17.6	11.1	7.3	5.0	3.6	2.6

3.4 Simulation Results

- Success Indexes Estimates – Efficiency Effect

Range of b_i´s		Number of Players								
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	$\overline{CGI}(n)$	100	67.8	31.6	17.6	11.1	7.3	5.0	3.6	2.6

3.5 Main Results

- The paradox of the global commons (Barrett, 1994) applies to international fisheries: The more the need for cooperation the lower the success.
- The higher the number of players the higher are the gains from cooperation but the lower is the success of coalition formation.
- New entrants, joining the RFMO or not, increase the incentive of RFMO members to leave and decrease the incentive of non-members to join it.
- The prospects of stable cooperative agreements increase with players' cost asymmetry and decrease with the overall efficiency level.

5. Recent Developments

- Over the last decade, partition function games have been used to analyze International Fisheries Agreements.
- Long (2009) show that a minimum participation clause increases the prospects of cooperation.
- Long and Flaaten (2011) conclude that under Stackelberg leadership the prospects of cooperation are higher.
- Breton and Keoula (2012) conclude that higher cooperation is achieved if players are farsighted (they foresee that by deviating from a coalition they may trigger the deviation of other members).

5. Recent Developments

- Ekerhovd (2010) addresses the blue whiting fishery in the Northeast Atlantic. The author shows that the spatial distribution of the blue whiting has a key role on the stability of a cooperative agreement.
- Ellefsen (2013) studies the mackerel stock in the Northeast Atlantic. He shows that a new entrant into the fishery, due to a change in the migratory pattern of the stock, decreases the stability of the IFA.
- Oinonen et al. (2016) analyse the management of salmon stocks in the Baltic Sea. They show that accounting for the benefits from recreational fisheries leads to larger cooperation among countries.

6. Conclusion

- Game Theory, the theory of strategic interaction, can help to understand the forces that lead to conflict / cooperation in IFAs.
- A key message that emerges is that self-enforcing cooperative management of internationally shared fish stocks is generally difficult to achieve.
- The success of IFAs depends largely on the ability of RFMOs to deter free riding.
- Avenues for further research: Dynamic coalition formation games; Uncertainty and learning in fishery coalition games.

Thanks for your attention