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A constraint-based framework to study competition and cooperation in fishing

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ABSTRACT

In this paper, we present a simple framework to study competition, cooperation and bargaining options among fisheries when they operate under financial and technological constraints. Competition within constraints leads to a particular type of mathematical game in which the strategy choice by one player changes the strategy set of the other. By studying the equilibria and bargaining space of this game when players maximize either profit or yield, we show that differences in financial constraints among players lead to a tougher play, with a reduced bargaining space as the least constrained player can readily exclude another from the competition. The exacerbating effects of constraints on competition are particularly strong when players maximize yield. We discuss the significance of our results for fisheries management in a current context of financialization and technological development. We suggest that in order to maximize the chances of fruitful negotiations and aim towards a fair sharing of sea resources, it would be helpful to focus on leveling current differences in the constraints faced between competing fishing systems, notably by supporting local financial systems and technological control.

1. Introduction

Game theory is a powerful tool for the analysis of fishing systems and has offered useful theoretical guidance to organize the exploitation of our seas (e.g., Sumaila, 1999; Kaitala and Lindroos, 2007; Bailey et al., 2010; Hannesson, 2011). A game theoretical approach is particularly useful to understand the consequences of competition and cooperation when a natural resource is being exploited (e.g., Hannesson, 1997). Competition and cooperation in this context are usually understood by viewing the sharing of a fish resource as a prisoner's dilemma game (Feeny et al., 1996; Munro, 2009), in which players may choose to either restrain exploitation, or defect and exploit as much as possible. Here, competition results in common defection, the over-exploitation of fish resources, and a situation in which players earn less than if they had cooperated. By contrast, cooperation would result in joint restraint, sustainable fish resources and better payoff. A shift from a competitive relationship to a cooperative one is therefore necessary if the long term livelihood of fisheries is to be maintained.

In game theory, the transition from competition to cooperation brings to the foreground the concept of bargaining, which is at the heart John Nash's seminal works (Nash, 1950a,b, 1953). Briefly, bargaining is a negotiation process that leads players to share a resource in a way that provides a better payoff to all players than if they had competed. Successful bargaining results in a sharing that is accepted by all players, and such a sharing is said to be fair (Binmore et al., 1986). The failure of bargaining, by contrast, results in unresolved distributional conflicts, the impossibility of cooperation and over-exploitation due to competition.

The potential consequences of bargaining failure have been put forward explicitly by Alcock (2002), who argues that the collapse of cod in Canada in the 90s was at least partly due to a distributional conflict between small-scale and industrial fisheries. Alcock (2002) additionally points at the absence of theoretical tools to understand this type of distributional conflict. An absence which delayed conflict resolution and the transition towards cooperation, and in turn resulted in catch diminutions coming about too late. More broadly, the view that understanding competition, cooperation and the transition between the two through bargaining would help understand fishing crises is shared among several authors (Fearon, 1998; Alcock, 2002; Munro, 2009). Yet, few works have articulated fisheries problems in such terms (but see Hämäläinen et al., 1985; Kaitala, 1985; Armstrong, 1998).

Alcock's (2002) analysis is useful to highlight two important factors that influence the competitive and cooperative relationships among fishing systems. First, the conflict was caused by small-scale and industrial fisheries suffering different constraints, due in particular to differences in technical and financial states (Alcock, 2002).

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Technological progress (Squires and Vestergaard, 2013) and financialization (i.e. modernization and global expansion of financial tools, Epstein, 2005) have both been playing an increasingly important role in fisheries who increasingly rely on finance to purchase ever more advanced fleets. The two processes feedback on one another to constrain fisheries' scope of action as fisheries become increasingly dependent on technology to increase catch in order to repay finance.

Several game theoretical models applied to fisheries have highlighted how differences in constraints among players lead to asymmetrical competition. For instance, when effort is the strategic variable and is costly, this implicitly introduces constraints, which can lead to more aggressive competition (Hannesson, 2011). Differential costs among fishing systems, which indirectly results in differential constraints, also influence competition and can lead to the exclusion of the less efficient system (Arnason et al., 2000; Hannesson, 2013). Studies of financial constraints, meanwhile, have been placed in the contexts of investment irreversibility (Sumaila, 1994) and inequality in the access to investment (Aggarwal and Narayan, 2004). But how technological and financial constraints influence bargaining options and the transition to cooperation remains unknown. The need for further assessment of the constraining effects of technology and finance is further bolstered by many issues faced by fisheries other than distributional conflicts, such as the dangers of a rent-maximization principle in developing countries (Béné et al., 2010), or the economic and ecological stakes associated with deep-sea fishing (Norse et al., 2012).

The second factor thought to have led to a distributional conflict in Canada is that small-scale and industrial fisheries were aiming at fulfilling different objectives, such as subsistence vs. return on capital (Alcock, 2002). Most of the applications of game theory to fisheries have been based on the idea of profit maximization (i.e., when the game's payoff is profit, Hannesson, 2011, for review). But in complicated social–ecological systems such as fishing systems (Berkes et al., 2008), we are led to seriously consider who (e.g., boat skipper, firm owner, fishery, fleet, fishery manager, policy maker) maximizes what (e.g., catch, profit, capacity, well-being, pleasure, peace). More generally, ignoring the variety of payoffs in fishing systems has been argued to be potentially damaging for the articulation of efficient fisheries policies (Hilborn, 2007; Bromley, 2009). How different payoffs influence the transition from competition to cooperation among fishing systems, however, is still poorly understood.

In order to fill these gaps, we suggest here a simple game-theoretical framework to study competition, cooperation, and whether bargaining is possible, when fishing systems operate under financial and technological constraints. We use our framework to study the equilibria of a game between two fishing systems that seek to maximize either profit or yield. Our approach departs from previous works by (a) explicitly accounting for constraints; (b) being based on an equilibrium fisheries model (such as the Gordon–Schaeffer model), while many applications of game theory to fisheries are based on a bio-economic model due to Clark (1990), which is essentially a dynamical one; (c) focusing on the first transitioning steps from competition to cooperation, ignoring classical notions from cooperative game theory (e.g., coalitions and Shapley values, Arnason et al., 2000), and (d) comparing a game's outcome according to whether the payoff variable is profit or yield. In the light of our results, we formulate some recommendations to promote the long term co-existence of multiple fishing systems.

2. Model and results

2.1. A single fishing system under constraints

2.1.1. Model

In order to introduce our framework, we first represent in a stylized manner a single fishing system, which exploits a fish stock and sells its yield on a market. Such a fishing system could be a fishing country fishing in its exclusive economic zone. Throughout, upper- and lower-case symbols denote variables and parameters respectively (see Table 1 for a list of symbols).

Table 1
Variables, equations and parameters of the model. Values in this table are those used for the analysis of a single fishing system (Section 2.1).

Function or parameter	Symbol	Value	Unit
Effort	E		Unit of effort
Fishing capacity	K		Unit of fishing capacity
Yield	Y		Ton of caught fish
Fish stock	$S(Y)$	Eq. (2)	ton of fish
Price	$P(Y)$	Eq. (3)	$ per ton of fish
Cost	$F(Y)$	Eq. (4)	$ per ton of fish
Net profit	I	Eq. (5)	$
Virgin stock	s	5000	ton of fish
Effect of catches on stock	r	10	(ton of fish)/(ton of caught fish)
Catchability	q	0.01	(ton of caught fish)/(ton of fish in the sea × unit of effort)
Maximum price	a	500	$/(ton of traded fish)
Effect of offer on price	b	1	$/(ton of traded fish)^2
Fishing cost function (constant)[a]	g	100	$/(ton of caught fish)
Fishing cost function (stock dependency)[a]	h	1,000,000	$/(ton of fish)
Trade cost	m	50	$/(ton of traded fish)
Price of fishing unit	p	15,000	$/(unit of effort)
Rate of return	k	0.05	No unit

[a] See Eqs. (4), (A.5) and (A.6) for details.

Our model follows closely most conventional surplus production models (Haddon, 2010). We consider a fishing system that has a capacity K for harvest. It expends an effort E that cannot exceed capacity ($E \leq K$) into harvesting a fish stock that has a total biomass S. The yield Y from harvest depends on the level of stock S, as well as on effort E, according to the usual formula,

$$Y = \mathrm{q}\, SE, \tag{1}$$

where q is the fishing efficiency coefficient and represents the technological level of the fishing system. In turn, the biomass of fish stock S decreases with yield Y according to,

$$S(Y) = s - \mathrm{r}\, \mathrm{Y}, \tag{2}$$

where s denotes the level of biomass in the absence of fishing, and r captures the effect of fishing on biomass. The linear relationship between stock and yield that we use (Eq. (2)) is a first-order approximation of the relationship between yield and production used in conventional fisheries model (see Appendix A). This assumption simplifies analysis but our results should hold more generally (see Appendix B).

The profit of the fishing system depends on a balance of income and expenditures. Its only source of income is from sales. Its yield Y is sold on the market, with unit selling price P. We assume that the price decreases linearly with the total level of offer,

$$P(Y) = a - \mathrm{b}\, \mathrm{Y}, \tag{3}$$

where a is the maximum unit price and b is the decrease in unit price according to offer. This is a first-order approximation of the conventional inverse demand functions (see Appendix A for details).

The system faces three sources of expenditures. First, access to the market is costly, with each unit of yield having a marketing cost m. Second, fishing activity is costly. We make the standard assumption that unit fishing cost is stock dependent according to,

$$F(Y) = g + \frac{h}{S(Y)} \tag{4}$$

(see Smith, 1968 for a classical discussion about fishing costs functions in bio-economic fisheries models, and Appendix A for more details on Eq. (4)). Third, and most importantly for our analysis, we assume that