THE POTENTIAL FOR COOPERATION IN SHARED FISHERIES

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ABSTRACT

This paper studies the potential for cooperation in shared fisheries when the countries in the coalition act in a Stackelberg fashion with respect to the remaining singletons. An increase in the cooperation level is a social welfare improvement, leading to an increase in both the steady-state fish stock and total rent. We demonstrate that the outlook for cooperation is better within the Stackelberg fashion, where the coalition acts as a leader, than in the Cournot fashion. Self-financed transfers with commitments of the initial stable coalition will increase the level of cooperation. The theoretical findings are illustrated by a numerical example of how to reach stable full cooperation.

Keywords: Non-cooperative approach, regional fisheries management organization, shared fisheries, stable coalition, Stackelberg game.

INTRODUCTION

Internationally-shared fish resources account for as much as one-third of world marine capture fish harvest (Munro, Van Houtte and Willmann 2004). FAO (2003) has declared that the effective management of these resources represents one of the great challenges on the way to achieving sustainable fisheries. This paper focuses on shared resources with several interested parties. The South China Sea, fished by about ten countries, is one example to which this analysis may be applicable.

Exploitation of a fish stock shared by a limited number of agents involves strategic choices. The theory of fisheries games before 1995 had concerned the case of just two agents (see e.g. Munro (1979) for an early contribution, Munro (1991) and Sumaila (1999) for reviews and Armstrong and Flaaten (1991) for an application). It is a fact, however, that many important stocks enclosed by the 200-mile limit are shared by two or more coastal states and the straddling of some fish stocks outside the 200-mile limit means they are accessible by fleets of any nationality (Hannesson 1997). The last decade has produced literature using the cooperative approach to deal with the potential of cooperative management issues of a shared fish stock when the number of agents involved is greater than two. For example, Kaitala and Lindroos (1998) and Lindroos (2004) use the characteristic function game to obtain fair-sharing solutions of surplus benefits from full cooperation. Once the number of players exceeds two, however, the possibility of sub-coalitions forming among players arises. Moreover, non-compliance and free riding behaviour – 'non-compliance' means cheating by participants in a cooperative arrangement and 'free riding' refers to enjoyment by non-participants of the benefits of, or returns from, a cooperative arrangement (see Munro, Van Houtte and Willmann 2004) – may be more difficult to control.

Utilization of shared fisheries is currently based on the legal frameworks proposed by the 1982 UN Convention on the Law of the Sea (UN 1982) – hereafter called LOS Convention – and the 1995 UN Fish Stock Agreement on the Conservation and Management of Straddling and Highly Migratory Fish Stocks (UN 1995) – hereafter called UNFSA. At the heart of the UNFSA lies the establishment of Regional Fishery Management Organizations (RFMO) to manage straddling and highly migratory fish stocks. According to Article 8 of UNFSA, only member states of RFMO, and states that apply the fishing restrictions adopted by it, shall have access to the regulated fishery resources. However, the UNFSA is binding only upon those States that are party to it. As of 26 October 2007, there are 67 States party to this agreement. Munro (2003) argued that under UNFSA, in the case of a straddling stock, a state or entity, which is not a member of the RFMO, found to be fishing in the high seas governed by the RFMO, would be deemed to be engaged, not in illegal fishing, but rather in unregulated fishing; thus he claimed that unregulated fishing can be seen as another form of free riding.

For these reasons, it is important for a RFMO managing a shared fish stock that this fishery is modelled with the equilibrium concept of a self-enforcing or stable agreement. A stable agreement made between parties, to our best knowledge, first proposed by D'Aspremont *et al.* (1983), and later coined by Barrett (1994, 2003), for use in his analysis of international environmental relations, is defined as a single coalition from which no member wishes to withdraw (the coalition is internally stable) and no non-member wishes to join (the coalition is externally stable). This supposes the use of the tools of non-cooperative game theory to model the formation of a RFMO.

To use the non-cooperative approach for examining the potential cooperation in utilizing a shared fish stock under the legal framework of LOS Convention and UNFSA, this paper considers a single coalition (including participants of the RFMO) through which members coordinate their strategies and assume that all other countries (non-participants) behave as singletons. Finus (2001) demonstrated that the Cournot and Stackelberg fashions are two extreme behaviours of the coalition and the remaining singletons. The former is a model in which the coalition chooses its fishing effort level with exogenous effort levels of singletons. This means that at one extreme the role of the coalition and singletons is assumed to be equal or they are assumed to be moved simultaneously. In the Stackelberg approach, the coalition takes into account its ability to manipulate the singletons' output to choose its own fishing effort with endogenous effort levels of singletons. This means that at the other extreme the coalition acts as a leader of the game or it has a strategic advantage.

Literature examining cooperative and non-cooperative consequences of a shared fishery in Cournot and Stackelberg fashions adopts both dynamic and static games. Levhari and Mirman (1980) compared results in the case of two countries and two periods. Benchekroun and Long (2002) argued that migratory fish that travel along the coastline of several nations are subject to sequential fishing and applied a Stackelberg fashion for a differential game of two agents. Naito and Polasky (1997) also employed the Stackelberg assumption with a two-period dynamic game model to investigate the leading role of a coastal country in utilizing a migratory fish stock when distant-water fishing nations are assumed to act as singletons. Hannesson (1997) used repeated games, with a Cournot assumption in the punishment period, to study factors affecting the stable grand coalition of a shared fishery. In contrast, Mesterton-Gibbons (1993) was the first to give an analysis of static non-cooperative fisheries games with a Cournot assumption. Ruseski (1998) adopted the static approach in a Cournot fashion in the case of two agents to examine the consequences of direct fishing subsidies on a shared fishery. Kronbak and Lindroos (2006) employed this game to examine fishermen and authorities forming coalitions. Pintassiglo and Lindroos (2007) used the static approach with a Cournot assumption of choosing fishing effort among coalitions to examine the coalition formation when there are two or more countries involved in a shared fishery. Long (2007) adopted the same method used by Pintassilgo and Lindroos (2006) to examine the effect of establishing a RFMO with effective enforcement in shared fisheries. The advantage of static games is that analytical results are easier to derive and interpret (Kaitala and Lindroos 2007). Moreover, since the static approach gives a good long-term prediction, it is consistent with UNFSA's aim of establishing a RFMO for sustaining long-term stability of shared fish stocks.

This paper uses a static Stackelberg approach combined with the classical Gordon-Schaefer model to examine the potential of cooperation in utilizing a shared fish stock. The findings are also compared to those in the other extreme case, the Cournot fashion, showed in Pintassilgo and Lindroos (2006) and Long (2007). The main contribution of this study is to show that (i) an increase in the cooperation level is a social welfare improvement; (ii) the perspective for cooperation is better within the Stackelberg fashion, where the coalition acts as a leader, than in the Cournot fashion; (iii) full cooperation not only leads to the highest levels of steady-state fish stock and total rent when the number of countries involved a shared fishery is constant, but also keeps them constant when more countries want to join the fishery; (iv) self-financed transfers with commitments of the initial stable coalition will increase the level of stable cooperation.

It is organized as follows. Section 2 presents the game and examines the potential of cooperation in shared fisheries. Section 3 gives a numerical example and discussion of how to reach a full cooperation. Finally, section 4 presents a policy implication and conclusion.

MODEL AND ANALYSIS

To focus on the formation process of a single coalition utilizing a shared fish stock, this study adopts a static Stackelberg approach combined with the classical Gordon-Schaefer model to examine the potential of cooperation in utilizing a shared fish stock. Apart from sequential fishing of many shared fish stocks, other motivations to investigate the cooperation where the countries in a coalition act in a Stackelberg fashion can be justified as follows. First, because the coalition has a relatively large fishing industry, it therefore has the power to act as a leader. Moreover, to ensure the long-term conservation and sustainable use of straddling and highly migratory fish stocks, UNFSA recommends the establishment of RFMO to manage these marine fish stocks. So secondly, the coalition participants who cooperate in forming a political bloc against outsiders have a stronger position in international politics than singletons who only pursue their own interests. Finally, comparison of this model and the one generated by a Cournot fashion, the other extreme, may give some important lessons for policymakers.

We assume that *N* countries share a fish stock, $A = \{1,...,N\}$. Harvest function, with equal catchability coefficient *q*, is the same across countries. Suppose that each country uses fishing effort $e_i \geq 0, i \in A$. For simplicity, the classic Gordon-Schaefer bio-economic model is used (see Clark 1976). Hence, the steady-state relation between fishing effort and stock is given by:

$$G(x) = rx(1-\frac{x}{K}) \text{ and } H = \sum_{i=1}^{N} h_i = qx\sum_{i=1}^{N} e_i \text{ , when } G(x) = H \Rightarrow rx(1-\frac{x}{K}) = qx\sum_{i=1}^{N} e_i. \quad (1)$$

Where *G(x)* is the logistic growth function; and h_i is the harvest of player *i*; *H* is the total catch; *K* is the carrying capacity for a fish stock of size *x*; *r* is the intrinsic growth rate.

We also assume a linear cost function for each country. In addition, the unit price of fish *p* and unit effort cost *c* are assumed to be equal for every country. Therefore, the welfare of country *i*, π_i , resource rent, the difference between revenue and cost of fishing becomes:

$$\pi_i = pqe_i x - ce_i. \quad (2)$$

To proceed assume that when a coalition is established its by-laws allow any of the *N* players to choose either to be a member or non-member of the coalition. Next, suppose that $s \in [0,1]$ is the share of countries that join the coalition – hereafter called the cooperation level. *Ns*, an integer, is the number of countries that form a coalition while *N(1-s)* is the number of singletons that stay outside the coalition. Assume that the coalition includes at least two agents. Thus, the partial cooperative case deals with a cooperation level in the range from *2/N* to *(N-1)/N*. The total fishing effort of the coalition is E_p, while each participant of the coalition uses e_p, such that $E_p = Nse_p$. Each non-participant (singleton) uses e_{np}, yielding a total fishing effort level of all singletons $E_{np} = N(1-s)e_{np}$. Total fishing effort of the fishery is $E = E_p + E_{np}$.

Stackelberg leadership of the coalition assumes that, when choosing its cooperative fishing effort, the coalition will take the reaction of the singletons into account (Finus 2001). This means that the coalition chooses its fishing effort with endogenous effort levels of singletons (Barrett 1994). In other words, the coalition acts as a leader of the game or it has a strategic advantage (Finus 2001).

Assume that each singleton chooses its fishing effort to maximize its resource rent, taking the fishing effort levels of remaining singletons and the coalition as given. That is

$$\underset{\{e_{np}\}}{\text{Max}} \; \pi_{np} = pqe_{np}x - ce_{np}$$

$$\text{Subject to } qx\left[e_{np} + [N(1-s)-1]\bar{e}_{np} + \bar{E}_p\right] = rx(1-x/K). \quad (3)$$

Where $\bar{e}_{np}$ and $\bar{E}_p$ are the fishing effort of each remaining singleton and the coalition, respectively, and are given. Next, the coalition chooses its fishing effort level by maximizing the collective rent while taking into account the behaviour of singletons. That is, the coalition chooses $E_p = Nse_p$ by solving the following maximization problem:

$$\underset{\{E_p\}}{\text{Max}} \; P_p = pqE_p x - cE_p$$

$$\text{Subject to } xq\left[N(1-s)e_{np} + E_p\right] = rx(1-x/K). \quad (4)$$

At equilibrium, $\bar{e}_{np} = e_{np}$ and $\bar{E}_p = E_p$. Solving (3) and (4), the fishing effort of a participant, non-participant and the fishery are, respectively (see Annex 0 for detail):

$$e_p = \frac{r(1-b)}{2qNs} \text{, } e_{np} = \frac{r(1-b)}{2q[N(1-s)+1]} \text{ and } E = \frac{r(1-b)}{2q}\left(2 - \frac{1}{[N(1-s)]+1}\right).$$

Where $b = \frac{c}{pqK} = \frac{x^{\infty}}{K}$ is the normalized and x^{∞} is the actual open-access equilibrium stock level ($0 < b < 1$). We exclude the cases $b = 0$ for costless harvesting and $b = 1$, which would imply stock extinction and no commercial harvesting. Furthermore,

The corresponding steady-state stock level: $x = K\left[1 - \frac{2N(1-s)+1}{2N(1-s)+2}(1-b)\right]$

The rent of each participant: $\pi_p = \frac{rpK(1-b)^2}{4Ns\left[N(1-s)+1\right]}$

The rent of each non-participant: $\pi_{np} = \frac{rpK(1-b)^2}{4\left[N(1-s)+1\right]^2}$

The total rent of the fishery is: $\prod = rpK(1-b)^2\left[\frac{2N(1-s)+1}{4\left[N(1-s)+1\right]^2}\right]$

Full cooperation exists when $s = 1$. Therefore there does not exist (3). The solution is given:

$$e(1) = \frac{r(1-b)}{2qN};\ x(1) = K\frac{1+b}{2};\pi(1) = \frac{rpK(1-b)^2}{4N};\prod(1) = \frac{rpK(1-b)^2}{4}. \qquad (5)$$

Clearly, the full cooperative solution is a special case of the above solutions.

The non-cooperation is not the case in the Stackelberg fashion since a coalition does not exist. Since, however, non-cooperation is the Nash Cournot equilibrium (Pintassilgo and Lindroos 2006), the result of this case is also presented for a later comparison between two extremes of behaviour. There does not exist (4). Therefore,

$$e(0) = \frac{2N}{(N+1)}e(1);\ x(0) = \frac{(1+Nb)}{(b+1)(N+1)}x(1);\pi(0) = \frac{4N}{(N+1)^2}\pi(1);\prod(0) = \frac{4N}{(N+1)^2}\prod(1).$$

It is easily verifiable that, when $N \geq 2$, the total rent of the fishery and the corresponding steady-state stock in the case of full cooperation are better than those in the case of non-cooperation, that is $\prod(1) > \prod(0)$ and $x(1) > x(0)$. Moreover, each country uses less fishing effort and is better off in full cooperation than in non-cooperation, that is, $e(1) < e(0)$ and $\pi(1) > \pi(0)$. When $N = 2$, there are only non-cooperation or full cooperation strategies. It is easy to see that each country is always better off in the case of full cooperation, as there is no incentive for a country to defect from the coalition. Therefore full cooperation always exists. In addition, one point that should be noted before we proceed is that at $s = 1/N$, there is only one agent in the coalition. Clearly, this is not the case of a RFMO. Hence, the continuing study only deals with $N > 2$ and $s \in \left[\frac{2}{N}, 1\right]$.

In examination of coalition formation, the three following important indicators will be considered. The first is the pay-off gap between a non-participant and a participant:

$$\mathrm{G} = \pi_{np}(s) - \pi_p(s) = \left[\frac{2Ns-(N+1)}{Ns\left[N(1-s)+1\right]^2}\right]\prod(1).$$

The second is the incentive indicator for defecting from the coalition, assuming that this single defection does not cause all the other parties to the coalition also to defect:

$$\mathrm{D} = \pi_{np}(s-1/N) - \pi_p(s) = \left[\frac{1}{\left[N(1-s)+2\right]^2} - \frac{1}{Ns\left[N(1-s)+1\right]}\right]\prod(1).$$

A non-positive defection indicator means that there will be no gain for a participant that leaves the existing coalition. This means that the coalition has achieved internal stability (see D' Aspremont *et al.* 1983). The third is the incentive indicator for free riding, which is given by:

$$\text{F} = \pi_{np}(s) - \pi_p(s + 1/N) = \left[\frac{1}{[N(1-s)+1]^2} - \frac{1}{(Ns+1)[N(1-s)]^2} \right] \prod (1).$$

A non-negative free riding indicator means that there exists a gain, including zero, for a singleton if it stays outside the coalition. Thus, the coalition has achieved external stability (see D' Aspremont *et al.* 1983).

UNFSA has called for and established a framework for cooperation in utilizing a shared fish stock. The above results lead to some bio-economic implications for cooperation. It is important to note that the following propositions are based on the assumptions of the stock growth and catch functions in (1) and revenue and cost functions in (2). The proofs for the propositions are presented in Annexes 1 – 4.

PROPOSITION 1. *If the level of cooperation increases,* $s \in \left[\frac{2}{N}, 1\right]$*, we have (for N > 2 and 0 < b < 1) the following implications:*

1.1. The steady-state fish stock level increases.
1.2. The total resource rent increases.
1.3. Rent of a non-participant increases, except when s = 1.
1.4. Rent of a participant decreases in $s \in \left[\frac{2}{N}, \frac{N+1}{2N}\right]$*, then increases in* $s \in \left[\frac{N+1}{2N}, 1\right]$*, and gets maximum level at full cooperation, s = 1.*
1.5. Income gap between a non-participant and a participant is zero when $s = \frac{N+1}{2N}$*; positive when* $\frac{N+1}{2N} < s \le \frac{N-1}{N}$*; negative when* $\frac{2}{N} \le s < \frac{N+1}{2N}$*, except when s = 1.*
1.6. Incentive indicators for defecting and free riding are not always positive.

The intuitive explanation behind Proposition 1.1 and 1.2 is that when more countries join the coalition, the total equilibrium fishing effort $E = \frac{r(1-b)}{2q}\left(2 - \frac{1}{[N(1-s)]+1}\right)$ will decrease. It leads to an increase in the steady-state fish stock. Since the positive effect of an increase in stock on resource rent is higher than the negative effect of this decrease in total fishing effort, this makes an increase in total rent of the fishery. These results were also found in the other extreme case with the Cournot fashion – the case that the coalition chooses its fishing effort with exogenous fishing efforts of singletons (see Long 2007). In general, an increase in the level of cooperation in shared fisheries is a social improvement, since not only the total rent of the fishery is higher, but the steady-state fish stock is also higher. This is a very important rationale for the call to establish a framework for cooperative use of shared fisheries.

The intuitive explanation for Propositions 1.3 to 1.6 is that in the traditional Stackelberg model, there is a strategic effect for the leader to expand harvest in order to get the follower to contract harvest (see Naito and Polasky 1997). Hence, there are situations (with sufficiently small coalitions), where a country is better off as a member of the coalition than it is outside the coalition, and as the coalition grows its members' rent deteriorates. When more countries join in the coalition, each of the remaining singletons will increase its fishing effort, leading to an increase in rent per non-participant. This is in line with the positive externality in fisheries in the case of Cournot fashion proved by Pintassilgo and Lindroos (2006).

Note that the participant's rent function does not demonstrate the same property as that in D' Aspremont *et al.* (1983), who showed that pay-off per agent within the cartel monotonically increases as the cartel size increases. The reason is that in a price leadership model the singleton behaves non-strategically, i.e., singletons behave as price-takers, not conceptualizing the impact of their action on the market price. In our case, however, the non-participants behave strategically by explicitly taking into account the negative effect their individual fishing efforts have on their resource rent via the steady-state fish stock. A similar result has been observed in Diamantoudi and Sartzetakis (2006) in the case of global pollution.

Propositions 1.5 and 1.6 show that some countries must get a higher resource rent when playing cooperation than when playing defect, irrespective of the number of other countries that play defect or cooperation. This means that playing defect is not a dominant strategy in this game. As argued above, it is important to find out the stable equilibriums for the game of sharing a fish stock. D'Aspremont *et al.* (1983) supposed two requirements for a stable coalition. First, it is a single coalition from which no member wishes to withdraw (the coalition is internally stable). The incentive indicator D for defecting is therefore non-positive. Second, no non-member wishes to join the existing coalition (the coalition is externally stable). This means that the incentive indicator F for free riding is non-negative. Note that *Ns* is an integer. These lead to Proposition 2 as follows:

PROPOSITION 2. *For a given number of countries participating in a commercial fishery (0 < b < 1) we have:*

- *2.1. Full cooperation is a stable coalition for* $N \leq 4$ *.*
- *2.2. When N > 4, a stable partial cooperation always exists at* s^**. Furthermore, when N = 2k (k is an integer value),* $s^* = \frac{N+2}{2N}$ *and when N = 2k +1,* $s^* = \frac{N+3}{2N}$*. Moreover, the size of the stable coalition (*s^**) is slightly larger than that for which the resource rent of the participants is at its minimum.*

The intuition behind Proposition 2 is that because of a strategic effect when the leader expands harvest in order to get the follower to contract harvest, when the number of countries involved in a shared fish stock is small enough (four or fewer) a country will recognize that it will be better off to play cooperate. If, however, more countries are involved in the fishery, an individual country may get more harvest if it leaves the coalition. At the level of cooperation $s = s^*$, no country wants to join or leave the coalition. In addition, Proposition 1.4 shows that the member's rent is minimum at the level of cooperation $s = \frac{N+1}{2N}$. Clearly, since *Ns* is an integer, the size of the stable coalition (s^*) is slightly larger than that for which the welfare of the participants is at its minimum.

Proposition 2 gives a more optimistic prediction for the prospects of cooperation in utilizing a shared fish stock than the other extreme case of Cournot fashion proposed by Pintassilgo and Lindroos (2006). They have proved that within the Cournot fashion of choosing fishing effort among the coalition and singletons, when there are three or more players the only Nash equilibrium coalition structure is the one formed by singletons. This means that when the number of countries involved in a shared fish stock, *N*, is more than two, Nash Cournot equilibrium is the non-cooperative case. Comparison of the result of Proposition 2 and non-cooperation leads to the next proposition.

PROPOSITION 3. *At the stable equilibrium in a Stackelberg fashion, the steady-state fish stock, total resource rent of the fishery and individual rent are higher than those of the Cournot Nash equilibrium when N > 2.*

Proposition 3 has an important implication for identification of the role of RFMO in utilizing a shared fish stock in two extreme cases. The first considers the fishing efforts of the remaining singletons to be endogenous in a Stackelberg fashion. In a Cournot assumption, RFMO considers the fishing efforts of fringes to be exogenous. Levhari and Mirman (1980) also compared a Stackelberg and Cournot model. In their duopoly model, each agent harvests only once per period. They demonstrated that given the stock size, sequential fishing (Stackelberg) yields greater equilibrium harvest and smaller equilibrium steady-state stock than does simultaneous fishing (Cournot). The reason is that there is a strategic effect when the coalition (leader) expands harvest in order to get the follower to contract harvest in a Stackelberg fashion (see Naito and Polasky 1997). However, the intuitive explanation for Proposition 3's result is that the strategic effect is present in our model as well, but it is dominated by the effect of reducing the number of singletons because of the open membership characteristic of the coalition. This leads to a higher level in steady-state fish stock, total rent of the fishery and individual rent in the Stackelberg equilibrium compared with those in the Cournot equilibrium. A similar result was found by Naito and Polasky (1997) in the case that a coastal state acts as the Stackelberg leader and sole harvester in the first stage, and then only distant-water fleets fish in the second stage. The reason for their result, however, is the effect of reducing the number of harvesters at the first stage because of the EEZ.

Up to now, on the assumption of a given number of countries, we have showed the positive effect of cooperation level on the fishery. Next, we relax this assumption to investigate the effect of the number of countries involved in this fishery when the level of cooperation is given. This effect is:

PROPOSITION 4. *An increase in the number of countries involved in a fishery implies:*

4.1. For s different from 1,

4.1.1. the steady-state fish stock level is reduced.

4.1.2. total rent is reduced.

4.1.3. the rent per country is reduced.

4.1.4. the level of cooperation at the stable equilibrium is reduced. There are, however, at least 50% countries joining the coalition.

4.2. For s = 1, full cooperation, the steady-state fish stock level and total rent are unchanged, but the rent per coalition member is reduced.

Proposition 4 suggests the negative effect of the number of countries involved in the shared fishery if the cooperation level is given. There are, however, two important points to be noted. The first is that when *N* is five or more and becomes larger, Proposition 2.2 shows that the level of cooperation at stable equilibrium will be reduced but the coalition includes at least half of the countries. The second is that at full cooperation the steady-state stock and total rent are unchanged regardless of the number of countries involved in the fishery. The intuition for the second is that at full cooperation the fishing effort to maximize the collective rent of the fishery is unchanged regardless of *N*. Moreover, since there is no singleton in the fishery at full cooperation, this result is the same in a Cournot fashion, the other extreme case. This may give an important rationale for the United Nations (UN) to call for full cooperation in shared fisheries.

Proposition 4 also gives an implication for the newcomer problem. Clearly, no one wants more countries involved in a shared fish stock. Assume that there now exists a level of cooperation s^0 and an additional country wants to join in the fishery. If the coalition does not accept this country as a new member, the fishery will become worse since there is not only a negative effect of an increase in *N*, but also a negative effect of a decrease in the level of cooperation. However, if the coalition admits the newcomer, a positive effect of an increase in the cooperation level may partly offset the negative effect of an increase in *N*. Clearly, a newcomer is not a serious problem in the full cooperative fishery, except that the former members have to share the rent with the newcomer. This is a rationale for the open membership characteristic of the coalition in shared fisheries.

A NUMERICAL EXAMPLE AND DISCUSSION

The second and fourth propositions suggest that the number of countries involved in a shared fishery has critical and negative effects on the potential for cooperative management. One of the important findings is that when five countries or more are involved in a shared fish stock, full cooperation is not a stable equilibrium. On the other hand, Proposition 4.2 also suggests that if full cooperation is reached the steady-state stock remains unchanged when the number of countries sharing a fish stock increases. The ambition of UNFSA is to create a duty on all states engaged in fisheries activities in waters under the management authority of a RFMO to cooperate through the RFMO in the conservation of the relevant fish stocks (Örebech, Sigurjonsson and McDorman 1998). How to increase the level of cooperation and to reach full cooperation is therefore a very important question for policymakers.

Proposition 1 gives an important signal that an increase in the level of cooperation is a social improvement, since not only the total rent of the fishery is higher, but also the steady-state fish stock is greater. These findings may imply that, at some level of cooperation, the move to a larger coalition is a Pareto's improvement. At full cooperation, the total rent of the fishery, the participant's rent and the steady-state fish stock are largest, but, within our modelling context, there is always incentive to break down the cooperation when five or more countries are involved a shared fishery. This implies that a better level of cooperation and then full cooperation in exploiting a shared fish stock may be reached if a suitable system of self-financed transfer with commitments is applied.

To illustrate the analysis above a numerical example is shown in Table I, with parameters $rpK(1–b)^2 = 1000$, $K = 1000$, $(1–b) = 0.4$ and $N = 10$.

Table I: A numerical example

s	x	π_p	π_{np}	$Ns\pi_p$	$N(1-s)\pi_{np}$	$\prod$	G	D	F
0.0	636.36	-	8.26	-	82.64	82.64	-	-	-5.62
0.2	622.22	13.88	3.08	27.77	24.69	52.46	-10.8	-5.62	-7.34

0.3	625.00	10.42	3.90	31.25	27.34	58.59	-6.52	-7.34	-5.02
0.4	628.57	8.92	5.10	35.71	30.61	66.32	-3.82	-5.02	-3.23
0.5	633.33	8.33	6.94	41.66	34.72	76.38	-1.39	-3.23	-1.39
0.6	640.00	8.33	10.00	50.00	40.00	90.00	1.67	-1.39	1.08
0.7	650.00	8.92	15.63	62.5	46.88	109.37	6.71	1.08	5.21
0.8	666.67	10.42	27.77	83.33	55.55	138.88	17.35	5.21	13.89
0.9	700.00	13.88	62.50	125.00	62.50	187.50	48.62	13.89	37.5
1	800.00	25.00	-	250.00	-	250.00	-	37.5	-

Table I shows that when $s < 0.6$ non-participants always do better by acceding to the coalition. On the other hand, starting at $s = 1.0$, one finds that participants always do better by withdrawing from the coalition whenever $s > 0.6$. At $s = 0.6$, there is no incentive to defect for all countries belonging to the coalition, and there is no incentive to join the coalition for all countries outside the coalition; the rent per coalition member is better than the individual rent of non-cooperation – the Cournot Nash equilibrium at $s = 0$. This means that the level of cooperation at the stable equilibrium is $s^* = \dfrac{10+2}{2\times 10} = 0.6$. Hence a coalition consisting of six participants is the only stable coalition for this problem. Moreover, the steady-state stock, total pay-off of the fishery and individual rent at the stable equilibrium are higher than those of the Cournot Nash equilibrium. Note that in a symmetric game and where there is simultaneous choice, it is impossible to predict which countries will sign and which will not, although Table I demonstrates that a partial cooperation with at least 6 participants will exist and some free riders (maximum 4) will get an attractive pay-off. Thus, this game framework is only focused on predicting the size of a stable coalition.

Clearly, if there is an increase in the level of cooperation from the stable equilibrium, the total rent of the fishery is higher. This means that there is a self-financed transfer to attract other players to join the coalition. Since, however, D is positive when s is equal to or larger than 0.7, there is an incentive for participants in the original coalition to defect. If only self-financed transfer from a stable coalition to the non-participants is applied, the level of cooperation could therefore not be improved

There may be various rules that can lead to the formation of larger stable coalitions. For simplicity, the suggestion of Carraro and Siniscalso (1993) about self-financed transfer with commitments is adopted to show how to increase the level of cooperation and then reach full cooperation, given the legal framework of LOS Convention and UNFSA.

The role of commitment to form a larger stable coalition has been discussed by Carraro and Siniscalco (1993). Assume that committed countries fully comply with their commitments. If all countries were committed to cooperation, obviously no free-riding would exist. Carraro and Siniscalco (1993) suggested that partial commitments, if associated with appropriate welfare transfers, can lead to larger stable coalitions. These tools to expand the stable coalition may be applicable to the case of highly migratory and straddling fish stocks regulated by LOS Convention and UNFSA.

For ease of discussion, let us go back to the numerical example in Table I. Suppose that there are m countries committed to cooperation regulated by Article 8 of UNFSA and that $10 - m$ countries do not commit to cooperation because of the unregulated fishing possibility. In order for it to be rational for committed players to pay others to expand the initial coalition, three conditions must obtain. The first is that the total transfer to induce some non-participants to join the coalition must be less than or equal to the gain that the m players achieve from expanding a larger coalition. Second, this transfer should compensate the non-participants for their loss in joining the coalition. Third, it should also offset incentives to defect from the new coalition (see Carraro and Siniscalco 1993).

Consider first the case of six countries in a stable initial coalition committed to the cooperation in Table I. The new stable coalition at the level of eight countries will be reached if the self-financed transfer is applied, since the gain of six committed countries ($6\times(10.42 - 8.33) = 12.54$) is larger than the transfer needed to prevent the defection of two new countries ($2\times(15.63 - 10.42) = 10.42$) and also there is clearly no loss for both new countries participating in the coalition. Moreover, it is easy to see that if there are seven countries committed to cooperation the stable full cooperation will be reached. The reason is that the gain of seven committed countries ($7\times(25 - 8.92) = 112.56$) is larger than the transfer needed to prevent the defection ($3\times(62.5 - 25) = 112.50$), and also there is clearly no loss for new countries joining the full cooperation. Hence, if m is 7 countries or more which have to be committed to cooperation regulated by Article 8 of UNFSA, full cooperation in utilizing a shared fish stock will be reached through the self-financed transfer.

In addition, if the sequential commitment procedure is adopted, full cooperation can be reached with the first six committed countries in the initial stable coalition. Clearly, when one more country joins the coalition, the gain of six committed countries ($6\times(8.92 - 8.33) = 3.54$) is larger than the loss incurred by the incoming country ($10 - 8.92 = 1.08$). Suppose that the seventh country, when entering the coalition, commits to cooperation. Clearly, the gain of seven committed countries ($7\times(10.42 - 8.92) = 10.5$) is larger than the loss incurred by the incoming country ($15.63 - 10.42 = 5.21$). Hence, the new stable coalition of eight countries is formed by the self-financed transfer. If this procedure is repeated with the ninth country, and after that with the tenth, a grand coalition of full cooperation can be achieved.

POLICY IMPLICATION AND CONCLUSION

This paper uses a static approach with the classical Gordon-Schaefer model to examine the potential of cooperation in utilizing a shared fish stock when the countries in the coalition act in a Stackelberg fashion in which the coalition takes fishing efforts of the remaining singletons as endogenous variables. We demonstrate that an increase in the cooperation level in utilizing a shared fish stock is a social welfare improvement, since it leads to an increase in both steady-state fish stock and total rent. This result is also found in the other extreme of a Cournot fashion in which the coalition takes fishing efforts of the remaining singletons as exogenous variables (see Long 2007). This means that the better level of cooperation is preferred from the social point of view. It may be an important rationale for a possible explanation of the UN call in 1995 for cooperation in utilizing a shared fish stock.

The study also shows that the strategic advantage of the coalition in a Stackelberg fashion is a reason for the more optimistic prospects of cooperation in utilizing a shared fish stock. Specifically, when the coalition acts as a leader, the grand coalition is a Nash equilibrium outcome only if there are no more than four countries involved in a shared fish stock. In addition, there is always a stable partial coalition for the exploitation of a shared fish stock when the number of countries involved in the fishery is more than four. Hannesson (1997) used the repeated game and also found that the number of agents who will cooperate in setting the exploitation rate for a shared fishery is quite limited. Pintassilgo and Lindroos (2006), in contrast, showed that a non-cooperative solution is the inevitable outcome when the number of agents is more than two and the grand coalition is a Nash equilibrium outcome only if there are two countries sharing a fish stock in the case of Cournot fashion. With a closer inspection of two stable equilibriums in Stackelberg and Cournot fashions, this paper also demonstrates that when N is greater than two, the strategic advantage of the coalition leads to a social welfare improvement, since it makes the steady-state fish stock, total rent and individual rent better though it reduces the number of singletons.

Full cooperation is the optimum in utilizing a shared fish stock in a Stackelberg fashion since it not only gives the highest levels of steady-state fish stock and total rent when N is constant, but also keeps them constant when more countries want to join the fishery. This is also recognized in the other extreme, the Cournot behaviour. It may be an important rationale for the suggestion of Lodge *et al.* (2007) that in each RFMO, the members should seek means of accommodating new members, such as allowing new members to purchase or lease fishing rights from existing RFMO members.

This study explicitly implies an incentive for any participant to defect the coalition at full cooperation when N is greater than four. It is also found in a Cournot fashion when N is greater than two (Pintassilgo and Lindroos 2006). Even the restrictions set by the UNFSA, prohibiting non-member states that do not abide by the regime of regional fishery organization in fishing the resource, the UNFSA is binding only upon those States that are party to it. Some countries may refuse to be party to the UNFSA to get the advantage of being free riders. This may be an explanation for the recommendation that the RFMO members should recognize the grave threat to the stability of the cooperative regime posed by illegal, unreported and unregulated fishing and work vigorously towards the suppression and elimination of such fishing (Lodge *et al.* 2007).

The self-financed transfer with commitments proposed by Carraro and Siniscalco (1993) is adopted as an example of using economic mechanisms to reach full cooperation in a Stackelberg fashion. Under the legal frameworks of the UNFSA and LOS Convention, some countries have to commit to cooperation. Using self-financed transfer with commitments, the goal of expanding the coalition can be reached. In the case of 10 countries sharing a fish stock, exemplified in Table I, full cooperation can be reached if there are at least seven countries committed to cooperation while there are six countries in the stable coalition. Moreover, if all countries in the initial stable coalition commit to cooperation, the full cooperation could be reached when the sequential commitment method is applied.

Finally, according to the present research, the prospects of cooperation in utilizing a shared fish stock are not unlikely if the coalition acts as a leader. Moreover, by means of self-financed transfer with commitments full cooperation can also be reached. This is an important implication for policymakers when discussing an agreement for establishing a RFMO to manage a shared fish stock. Future studies may consider countries sharing a fish stock with heterogeneous unit effort cost, catchability coefficient and unit harvest price. Case examination of more complex specifications of the resource rent, cost and harvest functions and dynamic analysis may also be a natural extension of the present research.

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ANNEXES

Annex 0. Proof of Maximization Problems

$(3)\Leftrightarrow \pi_{np} = A(1-b)e_{np} - \frac{Aq}{r}\left(\left[N(1-s)-1\right]\overline{e}_{np} + \overline{E}_p\right)e_{np} - \frac{Aq}{r}e_{np}^2$ where $A = pqK$. Taking the first derivative, we have $e_{np} = \frac{r(1-b)}{q[N(1-s)+1]} - \frac{\overline{E}_p}{[N(1-s)+1]}$. Replacing the result of e_{np} into (4), the maximization becomes $P_p = \frac{A(1-b)}{[N(1-s)+1]}E_p - \frac{qA}{r[N(1-s)+1]}E_p^2$. Taking the first derivative, we have $E_p = \frac{r(1-b)}{2q}$. Therefore, it is easy to get $e_p = \frac{r(1-b)}{2qNs}$ and $e_{np} = \frac{r(1-b)}{2q[N(1-s)+1]}$.

Annex 1. Proof of Proposition 1

$x(s) = K\left[1-\frac{2N(1-s)+1}{2N(1-s)+2}(1-b)\right]$ and $x(s+\frac{1}{N}) = K\left[1-\frac{2N(1-s)-1}{2N(1-s)}(1-b)\right]$

Clearly, $\frac{2N(1-s)+1}{2N(1-s)+2} > \frac{2N(1-s)-1}{2N(1-s)} \Rightarrow x(s+\frac{1}{N}) > x(s)$

$\prod(s) = \left[\frac{2N(1-s)+1}{[N(1-s)+1]^2}\right]\prod(1)$ and $\prod(s+\frac{1}{N}) = \left[\frac{2N(1-s)-1}{[N(1-s)]^2}\right]\prod(1)$. Clearly

$\prod(s+\frac{1}{N}) > \prod(s) \Leftrightarrow \left[\frac{2N(1-s)-1}{[N(1-s)]^2}\right] > \left[\frac{2N(1-s)+1}{[N(1-s)+1]^2}\right] \Leftrightarrow [N(1-s)+1][N(1-s)-1] + N^2s^2 > 0$. This is always satisfied when $s \in \left[\frac{2}{N}, 1\right]$.

$$\pi_{np}(s) = \frac{\prod(1)}{[N(1-s)+1]^2} \text{ and } \pi_{np}(s+\frac{1}{N}) = \frac{\prod(1)}{[N(1-s)]^2} \Rightarrow \pi_{np}(s) < \pi_{np}(s+\frac{1}{N})$$

if $s \in \left[\frac{2}{N}, \frac{N+1}{2N}\right), \frac{\partial \pi_p}{\partial s} < 0;$ if $s \in \left(\frac{N+1}{2N}, 1\right], \frac{\partial \pi_p}{\partial s} > 0;$ and if $s = \frac{N+1}{2N}, \frac{\partial \pi_p}{\partial s} = 0.$

G = $\left[\dfrac{2Ns-(N+1)}{Ns[N(1-s)+1]^2}\right]\prod(1) \Rightarrow$ G = 0 if $s=\dfrac{N+1}{2N}$, if $s \in \left[\dfrac{2}{N},\dfrac{N+1}{2N}\right)$, G < 0 and if $s \in \left(\dfrac{N+1}{2N},\dfrac{N-1}{N}\right]$, G > 0

At s = 3/N, D = $\dfrac{-(N-1)^2+3(N-1)-3}{3(N-2)(N-1)^2}<0$ and F = $\dfrac{-(N-3)^2+2(N-3)-1}{4(N-3)(N-2)^2}<0$.

Annex 2: The proof for Proposition 2

2.1. Full cooperation when $\pi(1) \geq \pi_{np}(\dfrac{N-1}{N}) \Rightarrow N \leq 4$ (see Proposition 1.3)

2.2. At s^* = (N+2)/2N if N = 2k (k is an integer value)

Condition 1: At the stable equilibrium, no member wants to leave the coalition (internal stable). This means:

$$\mathrm{D}=\pi_{np}(s^*-1/N)-\pi_p(s^*)\leq 0 \;\Leftrightarrow \frac{1}{4}(N+2)N \leq \frac{1}{4}(N+2)^2 \text{ (always be satisfied)}$$

Condition 2: At the stable equilibrium, no non-member wants to join the coalition (external stable). This means:

$$\mathrm{F}=-\pi_p(s^*+1/N)+\pi_{np}(s^*)\geq 0 \;\Leftrightarrow \frac{1}{4}N^2 \leq \frac{1}{4}(N+4)(N-2) \Leftrightarrow 2N-8\geq 0 \text{ (always be satisfied)}$$

Doing similarly when s^* = (N+3)/2N if N = 2k+1. Finally, Proposition 1.4 also suggests that the stable cooperation gives almost the lowest rent for the coalition's members.

Annex 3: Proof for Proposition 3

When N is fourth or less, full cooperation exists in a Stackelberg fashion. Hence, Proposition 3 is always satisfied. We now prove Proposition 3 for N larger than fourth. At s^* = (N+2)/2N if N = 2k (k is an integer value), we have:

$$x(\frac{N+2}{2N})=K\frac{Nb+1-b}{N} \text{ and } x(0)=K\left[\frac{1+Nb}{N+1}\right] \Rightarrow x(\frac{N+2}{2N})>x(0) \text{ (always be satisfied)}$$

$$\prod(\frac{N+2}{2N})=\frac{4(N-1)}{N^2}\prod(1) \text{ and } \prod(0)=\frac{4N}{(N+1)^2}\prod(1) \Rightarrow \prod(\frac{N+2}{2N})>\prod(0) \text{ (always be satisfied)}$$

$$\pi_p(\frac{N+2}{2N})=\frac{4}{N(N+2)}\prod(1) \text{ and } \pi(0)=\frac{4}{(N+1)^2}\prod(1) \Rightarrow \pi_p(\frac{N+2}{2N})>\pi(0) \text{ (always be satisfied)}$$

$$\pi_{np}(\frac{N+2}{2N})=\frac{4}{N^2}\prod(1) \text{ and } \pi(0)=\frac{4}{(N+1)^2}\prod(1) \Rightarrow \pi_{np}(\frac{N+2}{2N})>\pi(0)$$

Doing similarly when s^* = (N+3)/2N if N = 2k+1

Annex 4. Proof of Proposition 4

4.1. For s different from 1

$$x(N)=K\left[1-\frac{2N(1-s)+1}{2N(1-s)+2}(1-b)\right] \text{ and } x(N+1)=K\left[1-\frac{2N(1-s)+1+2(1-s)}{2N(1-s)+2+2(1-s)}(1-b)\right] \Rightarrow x(N)>x(N+1)$$

$$\prod(N)=\left[\frac{2N(1-s)+1}{[N(1-s)+1]^2}\right]\prod(1) \text{ and } \prod(N+1)=\left[\frac{2N(1-s)+1+2(1-s)}{[N(1-s)+1+(1-s)]^2}\right]\prod(1)$$

$$\prod(N)>\prod(N+1) \Leftrightarrow 2(1-s)^2N[N(1-s)+1]+(1-s)^2[2N(1-s)+1]>0 \text{ always be satisfied when } s\neq 1.$$

$$\pi_{np}(N)=\frac{\prod(1)}{[N(1-s)+1]^2} \text{ and } \pi_{np}(N+1)=\frac{\prod(1)}{[N(1-s)+1+(1-s)]^2} \Rightarrow \pi_{np}(N)>\pi_{np}(N+1)$$

$$\pi_p(N)=\frac{\prod(1)}{Ns[N(1-s)+1]} \text{ and } \pi_p(N+1)=\frac{\prod(1)}{(N+1)s[N(1-s)+1+(1-s)]} \Rightarrow \pi_p(N)>\pi_p(N+1)$$

It is easy to see that when N is going to infinite, the stable cooperation level (presented in Proposition 3) reaches half.

4.2. From (5), it is easy to see that in the case of full cooperation, s = 1, while the total rent of the fishery and stock is unchanged, the individual rent is decreasing in N.