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A Stackelberg Analysis of the Potential for Cooperation in Straddling Stock Fisheries

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Abstract *To ensure the long-term conservation and sustainable use of straddling fish stocks, the 1995 United Nations Fish Stock Agreement calls for the establishment of regional fisheries management organizations to manage them. This article studies the potential for cooperation in straddling stock fisheries when the cooperative coalition of countries acts as a Stackelberg leader against the remaining singleton countries. Within the Stackelberg fishing game with several interested parties, the result shows that an increase in the cooperation level leads to an increase not only in the steady-state fish stock, but also in the total rent of the fishery. Further, the outlook for cooperation is better within the Stackelberg game, where the cooperative coalition acts as a leader, than in the Cournot game. At the stable equilibrium of a Stackelberg game, not only is the steady-state fish stock higher, but also the total resource rent, participants' rent, and non-participants' rent are higher than those of the Cournot-Nash stable equilibrium. The new-entrant issue is a problem for the conservation of fish stock in the Stackelberg game. 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 and used to indicate possible ways forward for the South China Sea fisheries.*

Key words IUU fishing, non-cooperative game, regional fisheries management organization, straddling stock fisheries, stable coalition, Stackelberg game, South China Sea.

JEL Classification Codes Q22, Q27, R13, R58.

Introduction

Internationally shared fish resources account for as much as one-third of the world marine capture fish harvest (Munro, Van Houtte, and Willmann 2004). The FAO (2003) has declared that the effective management of these resources represents one of the great challenges to achieving sustainable fisheries. This article focuses on shared resources with several interested parties. The management of the marine resources in the South China Sea (SCS), where the resources are harvested by about 10 countries, is one example to which this analysis may be most relevant. The North-East Atlantic (NEA), fished by even

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more countries, is another example.[1] In both cases, several migratory species are seasonally more or less available for fishermen in different locations and countries. There is, however, one important difference between these two oceans. In the NEA case, 200 miles of internationally recognized exclusive economic zones (EEZs) have been established along almost all the coasts. This still leaves some important fishable areas in international waters between two or more EEZs. In the SCS, however, few EEZs are internationally recognized. Thus, the establishment of international arrangements that limit the international race for fish is still needed in some important fishing areas of the world. This article is a theoretical contribution to the management of straddling fish stocks—one type of shared fish stock (Bjørndal and Munro 2007)—that crosses the EEZ boundaries into the adjacent high seas where the resources are subject to exploitation by so-called distant-water states.

The exploitation of a fish stock shared by a limited number of agents involves strategic choices. The theory of fisheries games before 1993 concerned cases of just two agents (see *e.g.*, Munro (1979) for an early contribution; Kaitala (1986), Munro (1991), Sumaila (1999), and Lindroos, Kronbak, and Kaitala (2007) for reviews; Kaitala and Pohjola (1988) and Armstrong and Flaaten (1991) for applications). However, many important stocks in the EEZs are shared by two or more coastal states, and the straddling of some fish stocks outside the EEZs means they are accessible by fleets of any nationality (Hannesson 1997). Kaitala and Munro (1993, 1995), Bjørndal *et al.* (2000), and Bjørndal and Munro (2007) have considered the management issues of a shared fish stock when the number of agents involved is greater than two. The last decade has produced literature using the cooperative approach to deal with the potential of cooperation when three or more countries exploit a fish stock. 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 both add to the complexity of the problem: 'non-compliance' refers to 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 (Munro, Van Houtte, and Willmann 2004).

The utilization of a shared fish stock is currently based on the legal frameworks proposed by the 1982 United Nations Convention on the Law of the Sea (UN 1982)—hereafter called the LOS—and the 1995 United Nations Fish Stock Agreement on the Conservation and Management of Straddling and Highly Migratory Fish Stocks (UN 1995)—hereafter called the UNFSA. At the heart of the UNFSA lies the establishment of Regional Fishery Management Organizations (RFMOs) to manage straddling and highly migratory fish stocks. These fish stocks, from hereon in, are simply referred to as straddling fish stocks (Bjørndal and Munro 2007). According to Article 8 of the UNFSA, only member states of RFMOs and states that apply the fishing restrictions adopted by them shall have access to the regulated fishery resources. However, the UNFSA is binding only upon those states that are party to it. As of 25 September 2008, there were 71 states party to the UNFSA (UN 2008). Munro (2003) argued that, under the UNFSA, in the case of a straddling stock, a state or entity that 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. Moreover, the incidence of illegal, unreported, and unregulated (IUU) fishing is pervasive in many parts of the world (FAO 2001). Lodge *et al.* (2007) suggested that the RFMO members should recognize the grave threat to the stability of the cooperative regime posed by IUU fishing and work vigorously towards the suppression and elimination of such fishing.

[1] Counting the EU fishing nations as one makes the number of entities less than 10, but additional vessels from distant-water nations may appear.

For the reasons discussed above, it is important for the understanding of RFMO management of a straddling 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 agreements (IEAs), is defined as a single coalition from which no member wishes to withdraw (the cooperative coalition is internally stable) and no non-member wishes to join (the cooperative coalition is externally stable). For the purposes of the analyses of RFMOs, both cooperative and non-cooperative game theory is needed.

To use the non-cooperative approach for examining the potential cooperation in utilizing a straddling fish stock under the legal framework of the LOS and the UNFSA, this article considers a single coalition (formed by participants of the RFMO) through which members coordinate their strategies and assume that all non-participant countries behave as singletons. Finus (2001) demonstrated that the Cournot and Stackelberg games are two extreme modes of the game between the cooperative coalition and the remaining singletons. The Cournot game is a model in which the cooperative coalition and the singletons simultaneously maximize their payoffs, taking the effort levels of the others as given. In the Stackelberg game, the cooperative coalition takes into account its ability to influence the singletons' output by choosing its own fishing effort with endogenous effort levels of the singletons. This means that the cooperative coalition acts as a leader of the game, or it has a strategic advantage.

The literature examining the cooperative and non-cooperative consequences of a shared fishery by Cournot and Stackelberg games adopts both dynamic and static approaches. Levhari and Mirman (1980) compared results of the two games 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 game 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 provide analysis of static non-cooperative fisheries games with a Cournot assumption. Ruseski (1998) adopted the static approach in a Cournot game in the case of two agents to examine the consequences of direct fishing subsidies on a shared fishery. Kronbak and Lindroos (2006) also employed the static game to examine fishermen and authorities forming coalitions. Pintassilgo and Lindroos (2008) used the static approach with a Cournot assumption of choosing fishing effort among coalitions to examine the cooperative coalition formation when there are two or more countries involved in straddling stock fisheries. Long (2009) adopted the same method used by Pintassilgo and Lindroos (2008) to examine the potential of cooperation in straddling stock fisheries if an RFMO forms with an endogenous minimum participation level. Pintassilgo *et al.* (2010) extend the analysis of Pintassilgo and Lindroos (2008) by consideration of the asymmetry of harvesting costs. Kaitala and Lindroos (2007) argued that the advantage of static over dynamic games is that analytical results are easier to derive and interpret. In addition, since the static approach provides a good long-term prediction, it is consistent with the UNFSA's aim of establishing an RFMO to sustain the long-term stability of shared fish stocks (Long 2009).

To ensure the long-term conservation and sustainable use of straddling fish stocks, the UNFSA calls for the establishment of RFMOs to manage these marine fish stocks. Using the static Cournot game combined with the classical Gordon-Schaefer model for homogenous fishing countries, Pintassilgo and Lindroos (2008) have, however, demonstrated 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 stable equilibrium outcome only if there are two countries sharing a fish stock. Their result raises the question of whether the establishment of RFMOs to manage straddling stock fisheries under the UNFSA is stable and successful. Pintassilgo *et al.* (2010) have shown that the success of RFMOs is related to the level and asymmetry of harvesting costs in the static Cournot game. To investigate the potential for cooperation in straddling stock fisheries, this article assumes that an RFMO for managing a straddling stock fishery is sophisticated and acts as a Stackelberg leader, and that the singletons are naïve and act as the Stackelberg followers.[2] Hence, a Stackelberg game, the other extreme mode of the game between the cooperative coalition and the remaining singletons, is adopted in this study. Clearly, a comparison of this model and the one generated by a Cournot game may provide some important insights for policymakers.

This analytic approach has a much longer tradition in the literature on IEAs (*e.g.*, Barrett 1994; Finus 2003). Essentially, this literature focuses on emission reductions, and hence the provision of a public good (Pintassilgo *et al.* 2010). We, however, analyze the management of a common pool renewable resource—straddling stock fisheries under the UNFSA—with emphasis on the steady-state fish stock.

This article uses a static Stackelberg game combined with the classical Gordon-Schaefer model to examine the potential of cooperation in utilizing a straddling fish stock. The findings are also compared with the alternative mode of the strategic interaction, the Cournot game, shown in Pintassilgo and Lindroos (2008) and Long (2009). In this study, we show that *i*) an increase in the level of cooperation leads to an increase not only in the steady-state fish stock, but also in the total resource rent of the fishery; *ii*) the outlook for cooperation is better within the Stackelberg game, where the coalition acts as a leader, than in the Cournot game; *iii*) at stable equilibrium in a Stackelberg game, not only is the steady-state fish stock higher, but the total resource rent of the fishery, participants' rent, and non-participants' rent are also higher than those of the Cournot-Nash stable equilibrium; *iv*) the new-entrant issue is a problem for the conservation of this fish stock in the Stackelberg game; *v*) self-financed transfers with commitments of the initial stable coalition will increase the level of stable cooperation.

The article is organized as follows. The next section presents the game and examines the potential of cooperation in straddling stock fisheries. A numerical example and a discussion of how to reach a full cooperation will follow. Finally, the last section discusses policy implications and conclusions.

Model and Analysis

We assume that N countries exploit a straddling fish stock, $C = \{1,\ldots,N\}$. The harvest function, with equal catchability coefficient q, is the same across countries. Suppose that each country uses fishing effort $e_i \geq 0, i \in C$. For simplicity, the classic Gordon-Schaefer bio-economic model is used (Clark 1976):

$$\frac{dx}{dt} = G(x) - H,$$

[2] This problem setting may be relevant in cases when a single coalition, that includes participants of the RFMO, has more information about the shared fish stock than each singleton.

where G is the population renewal function and H is harvesting summed across all the countries. We assume that, $G(x) = rx(1 - \frac{x}{K})$ *and* $H = \sum_{i=1}^{N} h_i = qx\sum_{i=1}^{N} e_i$, where G is the logistic growth function, h_i is the harvest of player i, K is the carrying capacity for a fish stock, and r is the intrinsic growth rate. The steady-state relation between fishing effort and stock growth is given by $G(x) = H$, or:

$$rx(1 - \frac{x}{K}) = qx\sum_{i=1}^{N} e_i \tag{1}$$

We assume a linear cost function for each country. To be comparable with Pintassilgo and Lindroos (2008) and Long (2009), the unit price of fish, p, and unit effort cost, c, are assumed to be constant and equal for every country. Therefore, the welfare of country i, π_i, resource rent, the difference between revenue, and cost of fishing are given as:

$$\pi_i = pqe_i x - ce_i. \tag{2}$$

To proceed, assume that when a cooperative coalition is established, it—under the UNFSA—allows any of the N players to choose either to be a member or a non-member of the cooperative coalition. In addition, assume that the coalition's participants fully comply with the terms of agreement. Next, suppose that $s \in [2/N, 3/N, ..., (N-1)/N]$ is the fraction of countries that join the cooperative 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 cooperative coalition. Thus, the cooperative coalition includes at least two agents. 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 cooperative coalition is E_p, while each participant of the cooperative 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 the singletons $E_{np} = N(1–s)e_{np}$. The total fishing effort of the fishery is $E = E_p + E_{np}$.

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

To be comparable with Pintassilgo and Lindroos (2008) and Long (2009), assume that each singleton chooses its fishing effort to maximize its resource rent, taking the fishing effort levels of the remaining singletons and the cooperative coalition as given:

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

subject to:

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

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

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

subject to:

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

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

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

where $b = \dfrac{c}{pqK} = \dfrac{x^{\infty}}{K}$ is the normalized coefficient and x^{∞} is the actual open-access equilibrium stock level, respectively. We exclude the cases $b = 0$ for costless harvesting and $b = 1$, which would imply stock extinction and no commercial harvesting. Therefore, $0 < b < 1$. Furthermore, the corresponding steady-state stock level becomes $x = K\left[1 - \dfrac{2N(1-s)+1}{2N(1-s)+2}(1-b)\right]$. The rent of each participant is $\pi_p = \dfrac{rpK(1-b)^2}{4Ns\left[N(1-s)+1\right]}$, and the rent of each non-participant is $\pi_{np} = \dfrac{rpK(1-b)^2}{4\left[N(1-s)+1\right]^2}$.

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

Full cooperation exists when $s = 1$, in which case (3) is meaningless. The fully cooperative solution is given (Long 2009):

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

Note that the fully cooperative solution is a special case of the above solutions.

Non-cooperation occurs when no coalition exists in the Stackelberg game. Since non-cooperation results in the Nash-Cournot stable equilibrium (Pintassilgo and Lindroos 2008), we obtain (Long 2009):

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

When $N = 2$, there are only non-cooperation or full cooperation strategies. It is easily verifiable that each country is always better off in the case of full cooperation. Therefore, full cooperation always exists (Long 2009). It should also be noted that at $s = 1/N$, there is no coalition. Clearly, this is not the case of an RFMO. Hereafter, we assume that $N > 2$ and $s \in \left[\frac{2}{N}, 1\right]$.

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

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

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

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

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

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

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

To ensure the long-term conservation and sustainable use of straddling fish stocks, the UNFSA has called for and established a framework for cooperation in utilizing these marine fisheries. 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 equation (1) and revenue and cost functions in equation (2). The proofs for the propositions are presented in Annexes 1–4.

Proposition 1: *If the level of cooperation in utilizing a straddling fish stock 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 The rent of a non-participant increases.
1.4 The 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 reaches the maximum level at full cooperation, s = 1.*

1.5 The income gap between a non-participant and a participant is larger than or equal to zero when $\frac{N+1}{2N} \le s \le \frac{N-1}{N}$ *and negative when* $\frac{2}{N} \le s < \frac{N+1}{2N}$*, except when s = 1.*

1.6 The incentive indicators for defecting and free riding are not always positive.

The explanation behind *Propositions 1.1* and *1.2* is that, when more countries join the cooperative coalition, the total equilibrium fishing effort, $E = \frac{r(1-b)}{2q}\left(2 - \frac{1}{[N(1-s)+1]}\right)$, will decrease. This 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 increases the total rent of the fishery. These results were also found in the other extreme case with the Cournot game (Long 2009). In general, an increase in the level of cooperation in straddling stock fisheries leads not only to higher steady-state fish stock, but also to higher total fishing rent. This is a very important rationale for the call to establish a framework for the cooperative use of straddling stock fisheries.

The explanation for *Proposition 1.3* is that, in the Stackelberg model, there is a strategic effect for the leader to expand harvest in order to get the follower to contract harvest (Naito and Polasky 1997). Hence, there are situations (with sufficiently small coalitions), where a country is better off as a member of the cooperative coalition than it is outside the cooperative coalition, and as the cooperative coalition grows, its members' rent deteriorates. When more countries join in the cooperative 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 the Cournot game proved by Pintassilgo and Lindroos (2008).

Proposition 1.4 can be justified as follows. Since there is a strategic effect for the cooperative coalition to expand harvest in order to get the singletons to contract harvest, if more countries join in the coalition, the participants' fishing effort will decrease. On the other hand, Proposition 1.1 demonstrates that, if more countries participate in the coalition, the steady-state fish stock will increase. Thus, there are situations (with sufficiently small coalitions) where the negative effect of a participant's fishing effort is still larger than the positive effect of the steady-state fish stock on a participant's rent, leading to a decrease in the participant's rent when there is an increase in the level of cooperation. At some degree of cooperation level, as the coalition grows, the situation becomes inverted, and an increase in cooperation level will lead to an increase in the participants' rent. This relationship implies the 'U' shape of the participants' rent regarding the level of cooperation in utilizing straddling stock fisheries in a Stackelberg game. Within a Cournot game, Long (2009) also found this relationship. However, the reason for his finding is the 'U' shape of the participants' fishing effort regarding the level of cooperation in the Cournot game.

Propositions 1.5 and *1.6* show that at some cooperation levels, a country will gain a higher resource rent when playing cooperation than when playing defect. This means that playing defect is not a dominant strategy in this game. As argued above, it is important to find the stable equilibriums for the game of sharing a fish stock. D'Aspremont *et al.* (1983) set two requirements for a stable coalition. First, it is a single coalition from which no member wishes to withdraw (the cooperative 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 cooperative 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: *A stable RFMO in a commercial straddling stock fishery* ($0 < b < 1$)

2.1 For a given number of countries participating, we have:

2.1.1 Full cooperation is a stable coalition for $N \leq 4$.

2.1.2 When $N > 4$, *a stable partial cooperation always exists at* s^*. *Specifically, 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.*

2.2 When $N > 4$, *if more countries are involved in the fishery, the level of cooperation at stable equilibrium is reduced. There are, however, at least 50% of countries joining the cooperative coalition.*

The intuition behind *Proposition 2.1* is that, because of a strategic effect, 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 cooperate. If, however, more countries are involved in the fishery, an individual country may gain more harvest if it leaves the cooperative coalition. At the level of cooperation $s = s^*$, no country wants to join or leave the cooperative coalition. In addition, *Proposition 1.4* shows that the members' rent is at its 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 rent of the participants is at its minimum. Finally, the explanation for *Proposition 2.2* comes directly from *Proposition 2.1.2* when N comes to infinity.

Proposition 2 gives a more optimistic prediction for the prospects of cooperation in utilizing a straddling fish stock than the other extreme case of the Cournot game proposed by Pintassilgo and Lindroos (2008). They have proved that, within the Cournot game of choosing fishing effort among the cooperative coalition and singletons, the Nash-Cournot stable equilibrium is the non-cooperative case when the number of countries involved in a shared fish stock, N, is more than two. A comparison of the result of *Proposition 2* and non-cooperation leads to the next proposition.

Proposition 3: *At stable equilibrium in a Stackelberg game, not only is the steady-state fish stock higher, but also the total resource rent of the fishery, participants' rent, and non-participants' rent are higher than those of the Cournot-Nash stable equilibrium when* $N > 2$.

Proposition 3 has an important implication for the role of an RFMO in utilizing a shared fish stock in two extreme cases. In the Cournot game, the RFMO and the singletons simultaneously maximize their payoffs, taking the effort levels of the others as given. The RFMO in the Stackelberg game, however, acts as a Stackelberg leader and takes into account its ability to influence the singletons' output by choosing its own fishing effort with endogenous effort levels of the singletons. Levhari and Mirman (1980) also compared a Stackelberg and a Cournot model. In their duopoly model, each agent harvests only once per period. They demonstrated that, given the stock size, a Stackelberg game yields a greater equilibrium harvest and a smaller equilibrium steady-state stock than does a Cournot game. The reason is that there is a strategic effect when the leader expands harvest in order to get the follower to contract harvest in a Stackelberg game (Naito and Polasky 1997). However, the 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 cooperative coalition. This leads to a higher level in the steady-state fish stock, total rent of the fishery, and individual rent in the Stackelberg equilibrium compared with those in the Cournot equilibrium.

Next, we investigate the new-entrant issue in straddling stock fisheries in this Stackelberg game. New entrants are previously inactive fishing countries which now enter a straddling stock fishery (*e.g.*, Pintassilgo and Costa Duarte 2001; McKelvey, Sandal, and Steinshamn 2003; and Pintassilgo *et al.* 2010). A reason for this may be that the relative costs of fishing (*i.e.*, opportunity costs) or the absolute costs of these countries have decreased, making fishing now profitable (Pintassilgo *et al.* 2010). Suppose some new players enter a straddling stock fishery. The next proposition considers the effect of new entrants on the potential for cooperation when three or more countries exploit a straddling fish stock within this Stackelberg game.

Proposition 4: *The new-entrant issue*

4.1 In any cooperative coalition,

4.1.1 if new players act as singletons, the steady-state fish stock level, the total rent of the fishery, and the rent per country are reduced.

4.1.2 if new players join the cooperative coalition, the steady-state fish stock level and the total rent are unchanged, but the rent per coalition member is reduced.

4.1.3 when $s \geq s^*$ *if new players join the cooperative coalition, the rent per coalition member is always higher than if the new players act as singletons.*

4.2 In a stable coalition ($N \geq 4$),

4.2.1 when $N = 2k$, *if the number of the new players is* $2d+1$ ($2d$), *then* $d+1$ (d) *new players join the RFMO and* d (d) *new players act as singletons* (*d is an integer, including zero*). *Moreover, if new players sequentially enter the fishing game, the* $2d+1^{th}$ *entering player joins the cooperative coalition and the* $2d^{th}$ *entering player acts as a singleton such as the first entering player joins the cooperative coalition, the second entering player acts as a singleton, and so on.*

4.2.2 when $N = 2k+1$, *if the number of the new players is* $2d+1$ ($2d$), *then* d (d) *new players join the RFMO and* $d+1$ (d) *new players act as singletons. Moreover, if new players sequentially enter the fishing game, the* $2d^{th}$ *entering player joins the cooperative coalition and the* $2d+1^{th}$ *entering player acts as a singleton such as the first entering player acts as a singleton, the second entering player joins the cooperative coalition, and so on.*

Proposition 4.1.1 suggests the negative effect of new entrants on the potential for cooperation if the new players act as singletons. This is consistent with Pintassilgo *et al.* (2010) in the case of the Cournot game with heterogeneous harvesting costs. The intuition behind *Proposition 4.1.2* is that, because of a strategic effect, the cooperative coalition expands harvest in order to get the follower to contract harvest, and the former members have to share the rent with the new member(s) because of the open membership rule of an RFMO. Clearly, *Propositions 4.1.2* and *4.1.3* demonstrate that, at any cooperation level higher than or equal to s^*, the participation of new players in the existing coalition leads not only to higher steady-state fish stock, but also to higher total rent and individual rent than if the new players act as singletons. This is a rationale for the open membership characteristic of the cooperative coalition in straddling stock fisheries.

Assume that there exists a stable coalition managing a straddling stock fishery. Moreover, assume that if newcomers want to join the existing coalition, they will be accepted as new members, and the former members will share the rent with the new members. *Proposition 4.2* gives an important implication for the new entrant issue. If there is only a newcomer joining the fishery, it will participate in this coalition in the case $N = 2k$ but it will not in the case $N = 2k+1$. However, if the number of new entrants is two or more new players, approximately one half of them will have an incentive to act as singletons. This result shows that even if a stable coalition managing a straddling stock fishery with the open membership rule exists, the new-entrant issue is still a problem for the conservation of this fish stock in this Stackelberg game.

A Numerical Example and Discussion

The second proposition suggests that the number of countries involved in a straddling stock fishery has critical and negative effects on the potential for cooperative management. One of the important findings is that, when five or more countries are involved in a shared fish stock, full cooperation is not stable. The goal of the UNFSA is to create a duty on all states engaged in fisheries activities in waters under the management authority of an 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 sends an important signal that an increase in the level of cooperation leads not only to greater steady-state fish stock, but also to higher total rent of the fishery. At full cooperation, the total rent of the fishery, the participants' rent, and the steady-state fish stock are largest, but, within our modelling context, there is always an incentive to break down the cooperation when five or more countries are involved in a shared fishery. Next, we show that a higher level of cooperation and then full cooperation in exploiting a straddling fish stock may be reached if a suitable system of self-financed transfer with commitments is applied.

To comprehend, illustrate, and be pedagogical, a numerical example is shown in table 1, with parameters $rpK(1–b)^2 = 1000$, $K = 1000$, $(1–b) = 0.4$, and $N = 10$. Table 1 shows that when $s < 0.6$, non-participants always do better by acceding to the cooperative coalition. On the other hand, starting at $s = 1.0$, participants always do better by withdrawing from the cooperative coalition whenever $s > 0.6$. At $s = 0.6$, there is no incentive to defect for all the countries belonging to the cooperative coalition, and there is no incentive to join the cooperative coalition for all the countries outside cooperative coalition; the rent per coalition member is better than the individual rent of non-cooperation—the Cournot-Nash stable equilibrium at $s = 0$. This means that the level of cooperation at stable equilibrium is $s^* = \frac{10+2}{2\times 10} = 0.6$. Hence, a coalition consisting of six participants is the only stable coalition for this example. Moreover, the steady-state stock, total payoff of the fishery, and individual rent at stable equilibrium are higher than those of the Cournot-Nash stable equilibrium. Note that in a symmetric game, it is impossible to predict which countries will join the cooperative coalition and which will not, although table 1 demonstrates that a partial cooperation with at least six participants will exist, and some free riders (a maximum of four) will gain an attractive payoff. Thus, this game framework is only focused on predicting the size of a stable coalition.[3]

Table 1
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	–

[3] See Long (2009) for the further discussion of this issue.

Clearly, if there is an increase in the level of cooperation from stable equilibrium, both the steady-state fish stock and participant rent are higher. 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. Hence, if only a self-financed transfer from an initial stable coalition to the non-participants is applied, the level of cooperation could 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 Siniscalco (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 the LOS and the 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 the 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 straddling fish stocks regulated by the LOS and the UNFSA.

For ease of discussion, let us go back to the numerical example in table 1. Suppose that there are *m* countries committed to cooperation regulated by Article 8 of the 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 be obtained. The first is that the total transfer to induce some non-participants to join the cooperative 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 cooperative coalition. Third, it should also offset incentives to defect from the new coalition (Carraro and Siniscalco 1993).

Consider first the case of six countries in a stable initial coalition committed to the cooperation in table 1. 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 × (10.42 – 8.33) = 12.54) is larger than the transfer needed to prevent the defection of two new countries (2 × (15.63 – 10.42) = 10.42). Also, there is clearly no loss for both new countries participating in the cooperative coalition. Moreover, it is easy to see that, if there are seven countries committed to cooperation, stable full cooperation will be reached. The reason is that the gain of seven committed countries (7 × (25 – 8.92) = 112.56) is larger than the transfer needed to prevent the defection (3 × (62.5 – 25) = 112.50). Also, there is clearly no loss for the new countries joining the full cooperation. Hence, if *m* is seven countries or more, which have to be committed to cooperation regulated by Article 8 of the 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 cooperative coalition, the gain of six committed countries (6 × (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 cooperative coalition, commits to cooperation. Clearly, the gain of seven committed countries (7 × (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 article uses a static approach with the classic Gordon-Schaefer model to examine the potential of cooperation in utilizing a straddling fish stock when the cooperative coalition of countries acts as a Stackelberg leader in which the cooperative coalition takes the fishing efforts of the remaining singletons as endogenous variables. We demonstrate that an increase in the cooperation level in utilizing a straddling fish stock leads to an increase not only in the steady-state fish stock, but also in the total rent of the fishery. It is also found in the other extreme of a Cournot game in which the cooperative coalition and the singletons simultaneously maximize their payoffs, taking the effort levels of the others as given (Long 2009). This may be an important rationale for the establishment of RFMOs to manage straddling stock fisheries under the UNFSA.

We show that the strategic advantage of the cooperative coalition in a Stackelberg game is a reason for the more optimistic prospects of cooperation in utilizing a straddling fish stock than in a Cournot game. This result is also found in the literature on IEAs for the case of transboundary pollution (*e.g.*, Finus 2003). Specifically, we demonstrate that when the cooperative coalition acts as a leader, the grand coalition is a Nash stable equilibrium outcome only if there are no more than four countries fishing a straddling fish stock. In addition, there is always a stable partial coalition for the exploitation of a straddling fish stock when the number of countries involved in the fishery is more than four in the case of Stackelberg fishing game. Hannesson (1997) used the repeated game and found that the number of agents who will cooperate in setting the exploitation rate for a shared fishery is quite limited. Pintassilgo and Lindroos (2008), however, 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 stable equilibrium outcome only if there are two countries sharing a fish stock in the case of a Cournot game. Furthermore, with a closer inspection of the two stable equilibriums in Stackelberg and Cournot games, this article demonstrates also that, when N is greater than two, the strategic advantage of the cooperative coalition leads not only to an increase in the steady-state fish stock, but also to higher total rent, participants' rent, and non-participants' rent, since it reduces the number of singletons.

This study shows the negative effect of new entrants on the potential for cooperation if the new players act as singletons. This is consistent with Pintassilgo *et al.* (2010) in the case of a Cournot game with heterogeneous harvesting costs. Moreover, at any cooperation level higher than or equal to its stable cooperation level, the participation of new players in the existing coalition leads to higher steady-state fish stock, total rent, and individual rent than if the new players act as singletons. This 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 them to purchase or lease fishing rights from existing RFMO members. However, it is important to note that even if a stable coalition managing a straddling stock fishery with the open membership rule exists, the new-entrant issue is still a problem for the conservation of this fish stock in this Stackelberg game.

Full cooperation is the optimum in utilizing a straddling fish stock in the Stackelberg game since it gives not only the highest level of steady-state fish stock, but also the highest levels of total rent and participants' rent. However, there exists an incentive for any participant to defect from the cooperative coalition at full cooperation when N is greater than four. This is also found in a Cournot game when N is greater than two (Pintassilgo and Lindroos 2008). According to the UNFSA, states that do not abide by the regime of the RFMO are prohibited from fishing the straddling fishery resource. The UNFSA is, however, binding only upon those states that are party to it. Some countries may refuse to be party to the UNFSA to gain 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 IUU 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 game. Under the legal frameworks of the UNFSA and the LOS, some countries have to commit to cooperation. Using self-financed transfer with commitments, the goal of expanding the cooperative coalition can be reached. In the case of ten countries sharing a fish stock, exemplified in table 1, full cooperation can be reached if at least one non-participant commits to cooperation with six countries in the stable coalition. Moreover, if all the countries in the initial stable coalition commit to cooperation, full cooperation could be reached when the sequential commitment method is applied.

According to the present research, the prospects of cooperation in utilizing a straddling fish stock are likely if the cooperative coalition acts as a leader. Moreover, full cooperation can also be reached by means of self-financed transfer with commitments. Although this conclusion is not completely novel in the wider context of environmental economics, this article develops the analysis within the context of fisheries economics. The results bring an important implication for policymakers when discussing an agreement for establishing an RFMO to manage a straddling fish stock. It is, however, important to note that this study assumes that every member of the RMFO will comply with the terms of the agreement they have signed. This assumption means that every member will trust the compliance of others with the terms of agreement, with costless enforcement. If the cost of enforcing RFMO members' compliance with the terms of the agreement is high enough, there may not be any incentive for fishing countries to establish an RFMO for managing a straddling fish stock (Long 2009). This is probably one of the reasons for pervasive over-fishing around the world.

The results herein provide a background for discussing actual cases of sustainable management of marine resources utilized by several parties. One case is the SCS, bordered by 10 fishing nations, with several migratory species attracting seasonally varied activities of fishermen in different locations and countries. Currently, the SCS fisheries are open-access with excess fishing capacity in line with the non-cooperative modeling prediction. The existing fisheries organization in this area, the Southeast Asian Fisheries Development Center (SEAFDEC), is an autonomous intergovernmental body established in 1967 as a regional treaty organization to promote fisheries development. Currently, SEAFDEC includes eight countries bordering the SCS such as Brunei, Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. Its objective is to develop the fishery potential of the region through training, research, and information services to improve the food supply by rational utilization and development of the fisheries resources (SEAFDEC 2010). Thus, this may be the foundation for the formation of an RFMO. As demonstrated above, and in other papers quoted, both the resource rent and the steady-state fish stock may improve for the countries committed to cooperation, in particular if SEAFDEC acts as a Stackelberg leader. Next, the organization should negotiate with the People's Republic of China and Taiwan, the remaining countries bordering the SCS, for sharing benefits and responsibility for conserving fish stocks in this area. In the long term, full cooperation will bring not only the highest steady-state fish stocks, but also increased resource rent potential for all countries in the region. The fishery cooperation experience may spill over into other areas of cooperation in the SCS—one of the most contentious areas in the world in terms of both maritime boundary and territorial disputes.

Finally, following the vein of Pintassilgo *et al.* (2010), future studies may consider countries sharing a fish stock with a 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 this research.

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ANNEXES

Annex 0. Proof of Maximization Problems

$$(3)\ \Leftrightarrow \pi_{np} = A(1-b)e_{np} - \frac{Aq}{r}\Big(\big[N(1-s)-1\big]\,\overline{e}_{np} + \overline{\mathrm{E}}_p\Big)\,e_{np} - \frac{Aq}{r}e_{np}^2,$$

where $A = pqK$. Taking the first derivative and setting it equal to zero, we obtain $e_{np} = \frac{r(1-b)}{q\left[N(1-s)+1\right]} - \frac{\overline{E}_p}{\left[N(1-s)+1\right]}$. Replacing the result of e_{np} into (4), the maximization becomes:

$P_p = \frac{A(1-b)}{\left[N(1-s)+1\right]}E_p - \frac{qA}{r\left[N(1-s)+1\right]}E_p^2$. Taking the first derivative and setting it equal to zero, we obtain $E_p = \frac{r(1-b)}{2q}$. Therefore, it is easy to obtain $e_p = \frac{r(1-b)}{2qNs}$ and $e_{np} = \frac{r(1-b)}{2q\left[N(1-s)+1\right]}$.

Annex 1. Proof of Proposition 1

1.1

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

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

1.2

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

$$\Pi(s+\frac{1}{N})>\Pi(s)\Leftrightarrow\left[\frac{2N(1-s)-1}{\left[N(1-s)\right]^2}\right]>\left[\frac{2N(1-s)+1}{\left[N(1-s)+1\right]^2}\right]\Leftrightarrow\ \left[N(1-s)+1\right]\left[N(1-s)-1\right]+N^2s^2>0.$$

This is always satisfied when $s\in\left[\frac{2}{N},1\right]$.

1.3

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

1.4

$$\frac{\partial\pi_p}{\partial s}=\frac{2Ns-(N+1)}{Ns^2\left[N(1-s)+1\right]^2}\Pi(1).\ \text{Therefore,}$$

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

1.5

$$\text{G}=\left[\frac{2Ns-(N+1)}{Ns\left[N(1-s)+1\right]^2}\right]\Pi(1)\Rightarrow\ \text{if } s\ \in\left[\frac{2}{N},\ \frac{N+1}{2N}\right),\ \text{G}<0 \text{ and if } s\ \in\left[\frac{N+1}{2N},\ \frac{N-1}{N}\right],\ \text{G}\geq 0.$$

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

Annex 2: Proof of Proposition 2

2.1

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

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

<u>Condition 1</u>: At stable equilibrium, no member wants to leave the cooperative coalition (internally stable). This means:

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

<u>Condition 2</u>: At stable equilibrium, no non-member wants to join the cooperative coalition (externally stable). This means:

$F = -\pi_p(s^* + 1/N) + \pi_{np}(s^*) \geq 0 \Leftrightarrow \frac{1}{4}N^2 \leq \frac{1}{4}(N+4)(N-2) \Leftrightarrow 2N - 8 \geq 0$. This is satisfied when N is greater than four.

Similarly, when $s^* = (N+3)/(2N)$ if $N = 2k+1$.

Finally, *Proposition 1.4* also suggests that stable cooperation gives almost the lowest rent for the cooperative coalition's members.

2.2 It is easy to see that, when N is going to the infinity, the stable cooperation level (presented in *Proposition 2.1.2*) reaches half.

Annex 3: Proof of Proposition 3

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

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

$$x(\frac{N+2}{2N}) > x(0) \Leftrightarrow N(Nb+1) - Nb + (Nb+1) - b > N(Nb+1) \Leftrightarrow 1 - b > 0 \text{ (always be satisfied)}.$$

$$\Pi(\frac{N+2}{2N}) = \frac{4(N-1)}{N^2}\Pi(1) \text{ and } \Pi(0) = \frac{4N}{(N+1)^2}\Pi(1)$$

$$\Pi(\frac{N+2}{2N}) > \Pi(0) \Leftrightarrow N^3 < (N-1)(N+1)^2 \Leftrightarrow N^2 - N - 1 > 0 \text{ (always be satisfied when } N > 4).$$

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

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

(always be satisfied).

Similarly, when $s^* = (N+3)/(2N)$ if $N = 2k+1$.

Annex 4. Proof of Proposition 4

Denote that: $Ns = w$, the number of countries participating in a cooperative coalition; and $N(1-s) = n$, the number of countries acting as singletons. Therefore,

$$x = K\left[1 - \frac{2n+1}{2n+2}(1-b)\right],\ \pi_p = \frac{\Pi(1)}{w(n+1)},\ \pi_{np} = \frac{\Pi(1)}{(n+1)^2}, \text{ and } \Pi = \left[\frac{2n+1}{(n+1)^2}\right]\Pi(1).$$

4.1.1 When w is a constant,

$$\frac{\partial x}{\partial n} = -K(1-b)\frac{1}{2(n+1)^2} < 0; \frac{\partial \pi_p}{\partial n} = -\frac{\Pi(1)}{w(n+1)^2} < 0; \frac{\partial \pi_{np}}{\partial n} = -\frac{2\Pi(1)}{(n+1)^3} < 0; \frac{\partial \Pi}{\partial n} = -\frac{2n\Pi(1)}{(n+1)^3} < 0.$$

4.1.2 When w increases, the steady-state fish stock, total rent, and non-participants' rent are unchanged. However,

$$\frac{\partial \pi_p}{\partial w} = -\frac{\Pi(1)}{(n+1)w^2} < 0.$$

4.1.3 Assume that there are l new players.

At $s^* = (N+2)/(2N)$ if $N = 2k$, we have: $w = Ns^* = (N/2) + 1$ and $n = N(1-s^*) = (N/2)-1$. Clearly, when $s \geq s^* \Rightarrow w \geq n+2$.

If new players (l) act as singletons, the coalition's member rent is:

$$\pi^1{}_p = \frac{\Pi(1)}{w(n+l+1)}.$$

If they join the cooperative coalition, the coalition's member rent is:

$$\pi^2{}_p = \frac{\Pi(1)}{(w+l)(n+1)}.$$

$$\pi^2{}_p \geq \pi^1{}_p \Leftrightarrow \frac{\Pi(1)}{(w+l)(n+1)} \geq \frac{\Pi(1)}{w(n+l+1)} \Leftrightarrow w \geq n+1.$$

This is always satisfied (Q.E.D).

Similarly, when $s^* = (N+3)/(2N)$ if $N = 2k+1$.

4.2. $s^* = (N+2)/(2N)$ if $N = 2k$ and $s^* = (N+3)/(2N)$ if $N = 2k+1$ (k is an integer value).

4.2.1 When $N = 2k$, the cooperative coalition is stable at $s^* = (2k+2)/(4k)$. Hence, the number of countries participating in this stable coalition is $w = Ns^* = k+1$. If there is an additional country joining the fishery, then the number of countries involved in the fishery is now $2k+1$ (N_1). The coalition is now stable at $s_1^* = (N_1+3)/(2N_1)$. The number of countries in the cooperative coalition is $w_1 = N_1 s_1^* = (2k+4)/2 = k+2$. Since $w_1 = w+1$, the first new player joins the existing cooperative coalition. Next, assume that the second new player joins this fishery game. Then, the number of countries involved in the fishery is $2k+2$ (N_2). The coalition is stable at $s_2^* = (N_2+2)/(2N_2)$. The number of countries in the stable cooperative coalition is $w_2 = N_2 s_2^* = (2k+4)/2 = k+2$. Since $w_2 = w_1$, the second new player acts as a singleton. Next, assume that the third new player joins this fishery game. Then, the number of countries involved in the fishery is $2k+3$ (N_3). The coalition is stable at $s_3^* = (N_3+3)/(2N_3)$. The number of countries in the stable cooperative coalition is $w_3 = N_3 s_3^* = (2k+6)/2 = k+3$. Since $w_3 = w_2+1$, the third new player joins the existing coalition. The procedure is similar for the fourth new player and so on. Hence, if there are $2d+1$ ($2d$) new players joining the fishery, $d+1$ (d) new players participate in the existing coalition, and d (d) new players act as singletons. Moreover, the new coalition is also stable.

4.2.2 Similarly, when $N = 2k+1$.