REGIONAL FISHERY MANAGEMENT ORGANIZATION WITH A SELF-FINANCED ENFORCEMENT MECHANISM IN SHARED FISHERIES

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ABSTRACT

In order to provide a rationale and mechanism for implementing responsible fisheries in practice, this paper examines the effect of establishing Regional Fishery Management Organisation (RFMO) with effective enforcement on cooperative possibilities in shared fisheries. The result shows that an increase in cooperation level is a social welfare improvement, and this is an important rationale in the establishment of RFMOs for managing shared fisheries. If an RFMO is established and participants commit full compliance (costless enforcement), the outlook for cooperation in shared fisheries is optimistic. However, the attractive incentive for asymmetric information sharing about compliance among the RFMO members may lead to non-cooperation. Therefore, the game framework is extended by introducing a self-financed enforcement mechanism to ensure compliance by the RFMO members (costly enforcement). The result demonstrates that a mechanism that RFMO members finance and empower an independent enforcement body with monitoring and sanctioning capabilities may be a solution for the protection of cooperation. In addition, at some participant's enforcement cost level, when it increases, an RFMO requires a greater participation level to enter into force. Consequently, if an RFMO forms, it not only results in the higher level of steady-state fish stock, but also may improve participant's rent.

Keywords: Cournot game, non-cooperative approach, regional fisheries management organisation, stable coalition, shared fisheries.

INTRODUCTION

Internationally shared fish resources account for as much as one-third of the world marine capture fishery harvest (Munro, Van Houtte and Willmann 2004). The effective management of such resources represents one of the great challenges on the way towards achieving sustainable fisheries (FAO 2003). Currently, utilising a shared fish stock is based on the legal frameworks of the 1982 UN Convention on the Law of the Sea (UN 1982) – hereafter called the 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 the UNFSA. The heart of the UNFSA consists of placing Regional Fishery Management Organisations (RFMOs) to manage straddling and highly migratory fish stocks.

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 two agents (for reviews, see Munro [1991] and Sumaila [1999], and for an application see Armstrong and Flaaten [1991]). However, there is the fact that many important stocks enclosed by 200-mile limits are shared by two or more coastal states and the straddling of some fish stocks outside the 200-mile limit where they are accessible to fishing fleets of any nationality (Hannesson 1997). Munro (2003) argued that in the case of straddling stocks, 'large numbers' can be expected to be the rule, not the exception. Once the number of players exceeds two, the possibility of sub-coalitions forming among players exists. Moreover, the non-compliance and free riding behaviours – 'non-compliance' means cheating by participants in a cooperative arrangement, while 'free riding', on the other hand, refers to the enjoyment of the benefits of, or returns from, a cooperative arrangement by non-participants (see Munro, Van Houtte and Willmann 2004) – may be more difficult to control. Lodge *et al.* (2007) have recommended that if an RFMO is to be stable, then one of the core issues, intra-RFMO compliance, must be resolved. Activities such as monitoring, control and surveillance are important in order to ensure effective enforcement of RFMOs (Lodge *et al.* 2007).

It is therefore important for an RFMO managing a shared fish stock to be modelled with the equilibrium concept of a self-enforcing or stable agreement. A self-enforcing agreement made between agents, as first proposed by D'Aspremont *et al.* (1983) and later used by Barrett (1994, 2003) 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.

Over the last decade, studies carried out have adopted the static non-cooperative game to address coalition formation when the number of agents sharing a fishery is greater than two, such as Pintassilgo (2003), Kaitala and Lindroos (2007) and Pintassilgo and Lindroos (2006). Kaitala and Lindroos (2007) argued that the advantage of static over dynamic games is that analytical results are easier to derive and interpret. Moreover, since the static approach gives a good long-term prediction, it is consistent with UNFSA's aim of establishing an RFMO for sustaining long-term stability of shared fish stocks. However, they do not consider the RFMO's enforcement issue in coalition formation in shared fisheries.

This study adopts the Cournot game framework used by Pintassilgo and Lindroos (2006) to examine the effect of establishing an RFMO with effective enforcement which assures the participant's compliance on cooperative possibilities in shared fisheries. The Cournot fashion means that the coalition chooses its fishing effort level with exogenous effort levels of singletons (see e.g. Finus 2001, Pintassilgo and Lindroos 2006). We start with the assumption that RFMO participants commit full compliance with the terms of their agreement (costless enforcement). Furthermore, the game is extended by introducing a self-financed enforcement mechanism for the RFMO to ensure effective enforcement of members' compliance (costly enforcement). For simplicity, non-compliance to the terms of agreement is understood to mean that a signatory will play non-cooperatively when the agreement requires that it plays cooperatively. To the best of my knowledge, Kronbak and Lindroos (2006) have offered the only previous fisheries enforcement study that has adopted the static non-cooperative game to examine the possibility of forming coalitions. Their model, however, focused on testing how control policy, set by centralised, partly centralised or decentralised authorities, influences the cooperative behaviour of the fishermen.

The main contribution of this paper is to show that within a Cournot game (i) an increase in cooperation level is a social welfare improvement; (ii) a non-cooperative solution is not the inevitable outcome when three countries or more are involved in a shared fishery if an RFMO with effective enforcement is established; (iii) a self-financed enforcement mechanism that members in an RFMO finance and empower an independent enforcement body with monitoring and sanctioning capabilities may be a solution for the protection of cooperation; and (iv) at some participant's enforcement cost level, when it increases, an RFMO requires a greater participation level to enter into force. Consequently, if an RFMO forms, it not only results in the higher level of steady-state fish stock, but also may improve participant's rent. Clearly, this result implies that it is rational for cooperation in utilizing a shared fishery and establishing a RFMO with a self-financed enforcement is a possible mechanism for responsible shared-fisheries in practice.

The next will present the game and examine the effect of establishing an RFMO with effective enforcement on the possibility of forming coalitions in both cases – costless and costly enforcement of RFMO member's compliance. Section 3 provides numerical analysis and discussion. Finally, Section 4 presents a summary and conclusion.

THE MODEL

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 that any of the N players can choose either to be a member or non-member of the coalition. Moreover, assume that signatories will comply with the terms of the agreement. Next, suppose that $s \in [0,1]$ is the share of countries that joint 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 who stay outside the coalition. Clearly, full cooperation and non-cooperation exist when $s = 1$ and $s = 0$, respectively. Assume that the coalition is real, and includes at least two agents. The case $s = 1/N$ is left out of this analysis since the real coalition does not exist. Moreover, it is similar to the case of non-cooperation within the Cournot game framework (see discussion below). Thus, the partial cooperation deals with the level of cooperation in the range from $2/N$ to $(N-1)/N$. The total fishing effort of the coalition is E_p, while each member of the coalition (participant) uses e_p, such that $E_p = Nse_p$. Similarly, each singleton (non-participant) uses e_{np}, yielding a total fishing effort level of all singletons as $E_{np}= N(1-s)e_{np}$. Total fishing effort of the fishery is $E = E_p + E_{np}$.

Costless Enforcement

To examine the coalition formation in the case of costless enforcement, the model used by Pintassilgo and Lindroos (2006) is adopted. They assume the Cournot fashion of choosing fishing effort among the coalition and singletons. This means that the coalition chooses its fishing effort level with exogenous effort level of singletons, or the coalition and singletons are assumed to move simultaneously (see e.g. Finus 2001 and Pintassilgo and Lindroos 2006). In addition, the notion of the cooperation level (s) is also introduced in the model to facilitate the obtaining of some new results. For partial cooperation, $s \in \left[\frac{2}{N}, \frac{N-1}{N}\right]$, each singleton chooses the fishing effort to maximise its 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 efforts of each remaining singleton and the coalition, respectively, and are given. $\bar{e}_{np} = e_{np}$ at equilibrium. The coalition chooses its fishing effort to maximise the collective rent, taking the fishing effort of all singletons as given. That is:

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

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

At the equilibrium, $e_{np} = \bar{e}_{np}$ and $E_p = \bar{E}_p$. Solving (3) and (4), fishing effort of a participant, non-participant and the fishery are, respectively (see also Pintassilgo and Lindroos 2006):

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

Where $b = \frac{c}{pqK} = \frac{x^\infty}{K}$ is the normalised and x^∞ 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, respectively. Furthermore (see Annex 0 for detail),

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

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

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

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

The full cooperative and non-cooperative solutions can easily be derived as follows. On the one hand, when s = 1, full cooperation exists. In this case, there does not exist (3). Therefore:

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

On the other hand, when s = 0, a coalition does not exist, this is the case of non-cooperation. Within a Cournot game framework, this case is clearly similar to the case when $s = 1/N$. However, to be consistent to the above definition of a coalition, which includes at least two agents, we move out the case $s = 1/N$. At non-cooperation, there does not exist (4). Hence, the non-cooperative solution is given by:

$$e(0) = \frac{2N}{(N+1)}e(1); x(0) = \frac{2(1+Nb)}{(1+b)(N+1)}x(1); \pi(0) = \frac{4N}{(N+1)^2}\pi(1); \prod(0) = \frac{4N}{(N+1)^2}\prod(1). \qquad (6)$$

It is easily verifiable that when $N \geq 2$, the total rent of the fishery and correspondent 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 $\pi(1) > \pi(0)$. In addition, when N = 2, Pintassilgo and Lindroos (2006) have proved that players gain by forming a cooperative agreement. Therefore, the continuing study only deals with $N > 2$ and $s \in [0,1]$, except for the case $s = 1/N$.

To examine the coalition formation, two important indicators will be considered. The first 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:

$$\text{D} = \pi_{np}(s-1/N) - \pi_p(s) = 4\left[\frac{1}{[N(1-s)+3]^2} - \frac{1}{Ns[N(1-s)+2]^2}\right]\prod(1). \qquad (7)$$

Pintassilgo and Lindroos (2006) have proved that the defection indicator is always positive, except in the case of non-cooperation. This means that there will be a gain for a participant that leaves the existing coalition if assuming that this single defection does not cause all the other parties to the coalition also to defect. Therefore, defection is the dominant strategy within the Cournot game framework in shared fisheries. In this study, we assume that non-compliance to the terms of agreement implies that a participant will play non-cooperatively when the agreement requires that it plays to cooperate. This, of course, is an extreme case, since it can be shown that non-compliance can entail only a slight deviation – a slight increase in fishing effort relative to the level prescribed by the agreement. However, the assumption can be justified as follows. Since defection is the dominant strategy, the implication of non-compliance to the terms of the agreement is that if the agreement can deter a unilateral withdrawal, it can easily deter a lesser deviation. To deter a lesser deviation requires a smaller punishment. If a larger punishment is credible, therefore, so will be a smaller punishment (see Barrett 1999). The second incentive indicator applies to free riding:

$$\text{F} = \pi_{np}(s) - \pi_p(s+1/N) = 4\left[\frac{1}{[N(1-s)+2]^2} - \frac{1}{(Ns+1)[N(1-s)+1]^2}\right]\prod(1). \qquad (8)$$

That a singleton always becomes worse off by becoming a member of the coalition has been proved by Pintassilgo and Lindroos (2006). This means that the free riding indicator is always positive, except in the case of full cooperation. Thus, there exists a gain for a singleton if it stays outside the coalition.

The UNFSA has developed a legal framework for cooperation for utilising 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 stock growth and catch functions in (1), and revenue and cost functions in (2). The proofs for the propositions are presented in Annexes 1 – 3.

Proposition 1: *If the level of cooperation increases,* $s \in [0,1]$ *except* $s = 1/N$*, 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 participant first decreases in $s \in \left[0, \frac{N+2}{3N}\right]$*, then increases in* $s \in \left[\frac{N+2}{3N}, 1\right]$*, and achieves maximum level at full cooperation, s = 1.*

The intuitive explanation behind Proposition 1.1 and 1.2 is that when more countries join the coalition, the total equilibrium fishing effort $E = \frac{r(1-b)}{q}\left(1 - \frac{1}{[N(1-s)]+2}\right)$ 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 makes an increase in total rent of the fishery. These results give an important implication for cooperation in shared fisheries when the number of countries involved is greater than two. This is that an increase in the level of cooperation is a social improvement, since not only the total rent of the fishery is better, but also the steady-state fish stock is better. Next, Propositions 1.3 can be justified as follows. If more countries join in the coalition, its collective fishing effort will increase. However, there are situations (with sufficiently small coalitions) where this positive effect on participant's pay-off is still smaller than the negative effect of an increase in the number of countries in the coalition, leading to a decrease in participant's rent. At some degree of cooperation level, as the coalition grows the situation becomes inverse and participant's rent increases. This relationship implies the 'U' shape of participant's rent regarding the level of cooperation. This finding, however, 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 conceptualising 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 that 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.

Pintassilgo and Lindroos (2006) showed that in the case of three or more players, the only Nash equilibrium coalition structure is the one formed by singletons. This means that playing non-cooperation is the dominant strategy in this game when *N* is larger than two. It is also easy to recognise this finding, since the defection indicator presented in (7) is always positive except in the case of non-cooperation. Clearly, Propositions 1.1 and 1.2 show that the Nash equilibrium is inefficient, since not only the aggregate rent of the fishery would be strictly increasing, but also the steady-state fish stock level is improving in the cooperation level (*s*). This gives a rationale for establishing a legal organisation for cooperation.

Assume that an RFMO is established with the purpose of managing and conserving a shared fish stock. Next suppose that every members 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 of enforcement. We will show that when three countries or more are involved in a shared fish stock, a non-cooperative solution is not the inevitable outcome if an RFMO with effective enforcement to assure the participant's compliance with the terms of agreement is established.

Let us see the coalition at the cooperation level s^{nc}, in the costless enforcement case, that satisfies the following condition (see e.g. Barrett [2003] and McEvoy and Stranlund [2006] for the cases of environmental agreement):

$$s^{nc} = \min \; s \,\middle|\, \pi_p(s) - \pi(0) \geq 0. \tag{9}$$

Since Proposition 1.3 suggests the 'U' shaped relationship between the RFMO members' pay-off and the level of cooperation, no participant wants to leave this coalition, and this is for four reasons. First, if any participant withdraws, the remaining members will recognise that their payoff is even worse than in the case of non-cooperation, and therefore the coalition will collapse. Second, at the cooperation s^{nc}, the participant rent is at least as great as that of non-cooperation. Third, every RFMO member trusts that if a country signs the agreement, it will comply with the terms of the agreement. Finally, if $\pi_p(s^{nc}) = \pi(0)$, the coalition at the cooperation level of s^{nc} should still be preferred to exist since the steady-state stock of the fishery clearly is greater than in the case of non-cooperation. This means that an RFMO either enter into force if there is at least Ns^{nc} countries ratifying to participate or may not be worthwhile at all. Hence, the RFMO will achieve internal stability at the cooperation level of s^{nc}. The first requirement for a stable agreement proposed by D' Aspremont *et al.* (1983) is then satisfied. The next requirement is that no non-member wishes to joint the RFMO; that is, the agreement is externally stable. Clearly, the free riding indicator in (8) shows that that there always exists a gain for a singleton if it stays outside the coalition. This means that the coalition has achieved external stability at the cooperation level of s^{nc} (see D' Aspremont *et al.* 1983). Therefore, s^{nc} is the stable level of cooperation when no member wishes to withdraw and no non-member wishes to join. This leads to the second proposition as follows:

Proposition 2: *For a given number of countries participating in a shared fishery (0 < b < 1) if an RFMO with costless enforcement is established, then:*

2.1. full cooperation is a stable coalition for $N \leq 4$.

2.2. a stable partial cooperation exists at the level of cooperation $s = s^{nc}$ *for* $N \geq 5$.

Proposition 2 gives some implications for establishing an RFMO managing a shared fish stock within a Cournot game framework in the case of costless enforcing of the RFMO members' compliance. Firstly, when no more than four countries are involved in a shared fishery, establishing an RFMO to manage the fish stock requires that all countries ratify and then it become legally binding on all signatories. Furthermore, in the case of five or more countries involved in a shared fish stock, s^{nc} is the minimum participation level for the existence of an RFMO. This means that an RFMO with costless enforcement in shared fisheries only enters into force if there are at least Ns^{nc} countries ratifying to join in the RFMO. This changes the incentives presented to the players in shared fisheries. This is the intuitive explanation for the difference from the findings shown by Pintassilgo and Lindroos (2006).

Realistically, however, it is not easy for nations of the RFMO to trust each other, and this is for two main reasons. First, (7) suggests that there always exists an incentive for defection or non-compliance. And second, they could not easily monitor each other's compliance perfectly and without cost. If the other participating countries are not able to observe acts of non-compliance, they will not automatically leave the agreement. This will harm the remaining countries in the RFMO because per member pay-off may be even lower than in the case of non-cooperation, which then leads to motivations for implementing some enforcement mechanisms so as to counteract the incentive to violate the terms of the agreement.

Costly Enforcement

We now relax the assumption that the RFMO's members fully comply with the terms of their agreement, as well as giving them the opportunity to invest in an independent enforcement body that is charged with maintaining compliance. For simplicity, assume that each RFMO member provides the same fixed amount of money T to an independent enforcement body that is capable of monitoring the participants with probability v for detection and punishment, and of penalising non-compliance with a fine f.

Firstly, let us see the models when each RFMO's participant finances T for an independent enforcement body. For each singleton, its behaviour is similar to the model presented in (3). The coalition chooses its fishing effort to maximise the collective rent, taking the fishing effort of all singletons as given. That is:

$$\underset{\{E_p\}}{\text{Max}}\ P^c{}_p = pqE_p x - cE_p - NsT$$

$$\text{Subject to } xq\left\lfloor N(1-s)\bar{e}_{np} + E_p \right\rfloor = rx(1 - x/K)\,. \tag{10}$$

Solving (3) and (10) similar to the case of costless enforcement, the correspondent steady-state stock, rent of a participant and non-participant and total fishery rent are, respectively:

$$x^c(s) = K\left[1 - \frac{N(1-s)+1}{N(1-s)+2}(1-b)\right] = x(s)\,,\ \pi^c{}_p(s) = \frac{rpK(1-b)^2}{Ns\left[N(1-s)+2\right]^2} - T = \pi_p(s) - T\,,$$

$$\pi^c{}_{np}(s) = \frac{rpK(1-b)^2}{\left[N(1-s)+2\right]^2} = \pi_{np}(s)\,,\ \prod{}^c(s) = rpK(1-b)^2\left[\frac{N(1-s)+1}{\left[N(1-s)+2\right]^2}\right] - NsT = \prod(s) - NsT\,.$$

Since contributing to enforcement is an additional cost of joining the RFMO, it may affect the potential cooperation in utilising a shared fish stock. Denote s^c as the stable level of cooperation in the case of costly enforcing of RFMO member's compliance as follows:

$$s^c = \min \; s \big| \pi_p(s) - T - \pi(0) \geq 0. \quad (11)$$

This gives the following proposition:

Proposition 3: *The effect of the participant's enforcement cost level of T is:*

3.1. *When* $0 < T \leq \pi_p(s^{nc}) - \pi(0) \Rightarrow s^c = s^{nc}$

3.2. *The stable cooperation with costly enforcement exists at* s^c ($s^c > s^{nc}$) *when* $\pi_p(s^c - 1/N) - \pi(0) < T \leq \pi_p(s^c) - \pi(0)$. *Next, when* $\pi_p(s^c - 1/N) - \pi(0) < T \leq \pi_p(s^c) - \pi(s^{nc})$, *the participant's rent is higher than that of the costless enforcement case.*

3.3. *When* $\pi_p(s - 1/N) - \pi(0) < T \leq \pi_p(s) - \{\pi_p(s - 1/N) - [\pi_p(s - 2/N) - \pi(0)]\}$, *the stable coalition with costly enforcement exists at* $s^c = s$ ($s > s^{nc} + 1/N$). *Moreover, its participant's rent is always higher than that of the stable coalition with costly enforcement at the cooperation level of* $s^c = s - 1/N$.

3.4. *When* $T > \pi(1) - \pi(0)$ *, it is not rational to establish the RFMO.*

The intuition behind this result is quite straightforward. Since *T* is an additional cost of joining the RFMO, more countries may be required to participate in the RFMO in order to make the agreement worthwhile. Thus, if an RFMO that is costly to enforce forms, membership in the RFMO will be no less, and will typically be greater, than if the RFMO could be enforced without cost. Consequently, the steady-state fish stock will be no less, and will typically be greater, than if the RFMO could be enforced without cost. Full cooperation associated with the highest level of steady-state fish stock will be reached when the enforcement cost of each participant is *T* that $\pi(\frac{N-1}{N}) - \pi(0) < T \leq \pi(1) - \pi(0)$. Moreover, Proposition 3.2 suggests that a stable coalition with costly enforcement exists at the cooperation level of s^c, when the enforcement cost of each participant, $T \in \left(\pi(s^c - 1/N) - \pi(0), \pi(s^c) - \pi(0)\right]$. Clearly, $\pi^c{}_p(s^c) = \dfrac{rpK(1-b)^2}{Ns^c\left[N(1-s^c)+2\right]^2} - T$ shows that the RFMO's participant rent is a decreasing function in the level of *T*. Hence, the participant's rent at the stable cooperation level of s^c will be preferred when *T* reaches the upper limit of $\pi_p(s^c - 1/N) - \pi(0)$.

Although monitoring makes information among RFMO participants about each other's compliance become perfect and symmetric, the threat of defecting from the existing coalition still exists, since the incentive for defection or non-compliance, $D^c = \pi^c_{np}(s - 1/N) - \pi^c{}_p(s) = D + T > 0$, is very attractive. Identifying fine *f* to remove the incentive for non-compliant behaviour is the next objective. Assume that monitoring capacity of the enforcer is a monotonically increasing function of the amount of funding provided by the RFMO's participants, and that monitoring consists of random audits of the participants. Each dollar of additional enforcement funding allows the number of random audits to increase by *m*. If each RFMO participant provides *T* to fund the enforcer, then the number of random audits the enforcer implements is *NsTm*. Consequently, the probability that any member is audited is $v = NsTm/Ns = Tm$ ($v \in [0,1] \Rightarrow T \in [0, 1/m]$). Assume that audits are perfectly accurate. Therefore, the expected penalty for non-compliance is $vf = Tmf$.

Assume that the RFMO's participants are risk neutral, and that they comply with the terms of the agreement if they are at least indifferent between compliance and non-compliance. Given an RFMO consisting of *Ns* members, a participant will comply if its rent from doing so is not less than its expected rent from non-compliance. A participant's rent from compliance is $\pi^c{}_p(s) = \dfrac{rpK(1-b)^2}{Ns\left[N(1-s)+2\right]^2} - T$, and its expected pay-off from non-compliance is $\pi^c{}_{np}(s-1/N)-T-Tmf=\dfrac{rpK(1-b)^2}{\left[N(1-s)+3\right]^2}-T-Tmf$. Therefore, an RFMO's participant complies with the terms of the agreement if and only if:

$$\pi^c{}_p(s)-\left[\pi^c{}_{np}(s-1/N)-T-Tmf\right]\geq 0 \Rightarrow f \geq \frac{1}{Tm}\left(\frac{rpK(1-b)^2}{\left[N(1-s)+3\right]^2}-\frac{rpK(1-b)^2}{Ns\left[N(1-s)+2\right]^2}\right).$$

Thus, the RFMO with costly enforcement is stable at the level of cooperation of s^c, if the fine is at least,

$$f(s^c)=\frac{1}{Tm}\left(\frac{rpK\ (1-b)^2}{\left[N\ (1-s^c)+3\right]^2}-\frac{rpK\ (1-b)^2}{Ns^c\left[N\ (1-s^c)+2\right]^2}\right). \tag{12}$$

Therefore, when no more than four countries are involved in a shared fishery, Propositions 2.1 and 3.1 show that this mechanism can lead to stable full cooperation when $0<T\leq\pi(1)-\pi(0)$ and a suitable minimum fine is used. Furthermore, when five countries or more are sharing a fishery, Propositions 2.2 and 3.2 – 3.3 show that a partial stable cooperation will exists under certain conditions of the participant's enforcement cost. However when T reaches the upper limit of $\pi_p(\frac{N-1}{N})-\pi(0)$, this mechanism can lead to stable full cooperation, resulting in not only the highest steady-state fish stock but also the highest participant's rent.

NUMERICAL ANALYSIS AND DISCUSSION

To illustrate the analysis, a numerical example is shown in the following table corresponding to each level of cooperation, with $rpK(1\text{-}b)^2 = 1000$, $K = 1000$, $(1\text{-}b) = 0.4$, $m = 0.1$, and $N = 20$.

Table I: A Numerical Example

s	x	π_p	π_{np}	$\prod$	F	D
0.00	619	-	2.27	45.35	-	0.00
0.10	620	1.25	2.50	47.50	1.58	1.02
0.15	621	0.92	2.77	49.86	2.00	1.58
0.20	622	0.77	3.09	52.47	2.39	2.00
0.25	624	0.69	3.46	55.36	2.81	2.39
0.30	625	0.65	3.91	58.59	3.27	2.81
0.35	627	0.63	4.44	62.22	3.81	3.27
0.40	629	0.64	5.10	66.33	4.44	3.81
0.45	631	0.66	5.92	71.01	5.22	4.44
0.50	633	0.69	6.94	76.39	6.19	5.22
0.55	636	0.75	8.26	82.64	7.43	6.19
0.60	640	0.83	10.00	90.00	9.05	7.43
0.65	644	0.95	12.35	98.77	11.23	9.05
0.70	650	1.12	15.63	109.38	14.26	11.23
0.75	657	1.36	20.41	122.45	18.67	14.26
0.80	667	1.74	27.78	138.89	25.42	18.67
0.85	680	2.35	40.00	160.00	36.53	25.42
0.90	700	3.47	62.50	187.50	56.65	36.53
0.95	733	5.85	111.11	222.22	98.61	56.65
1.00	800	12.50	-	250.00	-	98.61

Table I shows that when s is set at 0, there is no cooperation and the net benefit to each player is 2.27. Clearly, no player wishes to cooperate. When s = 0.1, the net benefit to the cooperator is 1.25, which is less than in the case of non-cooperation. At the other extreme, if s = 1, each player receives a net rent of 12.50. When a player decides to defect, s = 0.95, its rent increases to 111.11, which is clearly much higher than what the player could get by complying with the agreement. Under the perfect information of defecting behaviour among members, the coalition still exists since the pay-off to remaining members is still higher than in the case of non-cooperation. The situations are similar to the cases of s = 0.95 and s = 0.90. Clearly, in these cases the single defection does not cause all the other parties to the coalition also to defect. However, at the level of cooperation s = 0.85, it is easy to see that if any member withdraws, the entire cooperative regime will collapses. The reason is that at s = 0.85 if any member withdraws the individual rationality constraint that $\pi_p(s < 0.85) - \pi(0) \geq 0$ presented in (9) is not satisfied. The level of cooperation s = 0.85, in Table I, is the minimum participation level for the existence of an RFMO. Moreover, there is no-one outside the RFMO wanting to join since it has a higher pay-off. Thus, s = 0.85 is the state of stable partial cooperation in the case of costless enforcement. 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 17 participants will exist and some free riders (maximum 3) will get an attractive pay-off. Clearly, this game framework is only focused on predicting the size of the stable RFMO that can be established and enter into force.

Realistically, nations of the RFMO can not monitor each other's compliance perfectly and without cost in the case of asymmetric information. Table I shows that there is an attractive incentive for non-compliance at s = 0.85. This implies an incentive for asymmetric information sharing about their compliance with the terms of the agreement among the RFMO members. This problem gives a motivation for implementing some enforcement mechanisms to counteract the incentive to violate the terms of the agreement.

Assume that each RFMO member finances the same fixed amount of money T to an independent enforcement body. Moreover, each dollar of additional enforcement funding allows the number of random audits to increase by m. Firstly, when $0 < T \leq 0.08$ (the difference of 2.35 – 2.27), the state of stable equilibrium is still unchanged at the level of cooperation $s^c = s^{nc} = 0.85$. When $T = T^0$, the minimum fine f^0 in (12) can be identified. Consequently, the steady-state fish stock and non-participant's rent are unchanged. However, the participant's rent (2.35 – T) is worsened and always smaller than that of the costless enforcement case (2.35). At T = 0.08 (2.35 – 2.27), although the participant rent is only equal to individual pay-off in non-cooperation, the steady-state fish stock (680) is significantly higher than in the case of non-cooperation (619).

Secondly, when $0.08 < T \leq 1.20$ (the difference of 3.47 – 2.27), stable equilibrium exists at the level of cooperation s^1 = 0.90, called state 1. This leads to a higher steady-state fish stock (700) and non-participant's rent (62.50) compared to those in the case of costless enforcement. Interestingly, when $0.08 < T \leq 1.12$ (the difference of 3.47 – 2.35), the participant's rent is at least as large as in the case of costless enforcement. Thirdly, when $1.20 < T \leq 3.58$ (the difference of 5.85 – 2.27), stable equilibrium exists at the level of cooperation s^2 = 0.95, called state 2. This leads to a higher steady-state fish stock (733) and pay-off per member outside the coalition (111.11). Moreover, when $1.20 < T \leq 2.46$ (or $3.47 - 2.27 < T \leq 5.85 - (3.47 - (2.35 - 2.27))$ – see Proposition 3.3), the participant's rent will be higher than that at state 1. Interestingly, when $1.20 < T \leq 3.50$ (the difference of 5.85 – 2.35, see Proposition 3.2), the participant's rent is at least as large as in the case of costless enforcement. Finally, when $3.58 < T \leq 10.23$ (the difference of 12.50 – 2.27), stable equilibrium exists at the level of cooperation s^3 = 1, i.e., full cooperation. This leads to the highest steady-state fish stock (800). Moreover, when $3.58 < T \leq 7.85$ (or $5.85 - 2.27 < T \leq 12.50 - (5.85 - (3.47 - 2.27))$), see Proposition 3.3), the participant's rent is always higher than at state 2, and therefore it reaches the highest level. Furthermore, since the participant's rent is a decreasing function of T in this range, it will be preferred when T reaches the upper limit of 3.58 (5.85 – 2.27). It is also important to note that when $3.58 < T \leq 10.15$ (the difference of 12.50 – 2.35, see Proposition 3.2), the participant's rent is at least as large as in the case of costless enforcement. Of course, if $T > 10.23$, there is not rational to establish the RFMO.

Note that up to now, in order to examine the effect of participant's enforcement cost on cooperation in shared fisheries we implicitly assume that a fine can be freely chosen. Assume that a maximum fine is constrained (by law or convention). We will demonstrate that a stable RFMO can easily be predicted. For this example, suppose a maximum fine, f_{max} = 200. Table I and (14) tell us that if a stable RFMO exists at s^c = 0.85, then a minimum participant's cost, T_{min}, is 1.27 or $(27.78 - 2.35)/(200 \times 0.1)$. Similarly, if a stable RFMO will exist at s^c = 0.90, 0.95 and 1.00, then a minimum participant's cost, T_{min}, is 1.82, 2.83 and 4.93, respectively. Assume that each RFMO member provides T_{min} to an independent enforcement body. Clearly, a stable RFMO may exist at s^c = 0.95 ($1.20 < 2.83 \leq 3.58$) if participant's enforcement cost is 2.83 or at s^c=1.00 ($3.58 < 4.93 \leq 10.23$) if it is 4.93. Interestingly, steady-state fish stock (800) and participant's rent (7.57 or 12.50 – 4.93) at T = 4.93 is greater than those (733 and 3.02 or 5.85 – 2.83) at T = 2.83.

Finally, an important implication for shared fisheries within the legal framework of the LOS Convention and the UNFSA is suggested as the following justification. According to Article 8 of the 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. This means that there still exist some countries that do not commit to cooperation because of the possibility of unregulated fishing (see Munro 2003). Clearly, this result implies that under some certain conditions of enforcement cost, it is rational to establish an RFMO to manage a shared fishery even not all countries involved ratify the UNFSA, or the Illegal, Unreported and Unregulated (IUU) problem may occur. However, note that if some countries involved a shared fishery have a strong aversion to inequity, the large rent captured by free riders (see Table I) may prevent the establishment of an RFMO.

SUMMARY AND CONCLUSIONS

This study provides an important rationale for the UNFSA's call for cooperation in the utilisation of shared fishers. That rationale is that an increase in the cooperation level in shared fisheries leads to an increase in both steady-state fish stock and total rent. This means that the improved level of cooperation is preferred from a social point of view, and this is an important rationale for the establishment of RFMOs to manage shared fisheries.

This paper examines the effect of establishing an RFMO with effective enforcement on cooperation in shared fisheries within a Cournot game. If an RFMO with a minimum participation level is established and participants commit full compliance with the terms of their agreement, the result shows that full cooperation is a stable coalition when four countries or fewer share a fish stock, or that a stable partial cooperation will exist when five countries or more are involved in a shared fishery. This contrasts with Pintassilgo and Lindroos (2006), who concluded that a non-cooperative solution is the inevitable outcome when the number of agents is greater than two. Moreover, the grand coalition is a Nash equilibrium outcome only if there are two countries sharing a fish stock. The reason for the difference is that an RFMO only enters into force if there is a minimum participation level and participants commit full compliance. This changes the incentives facing the players in shared fisheries.

Realistically, however, nations may not observe each other's compliance perfectly without cost when there is an incentive for asymmetric information sharing about their compliance with the terms of the agreement among the RFMO members. This paper, therefore, extends the game framework used by Pintassilgo and Lindroos (2006) by introducing a self-financed enforcement mechanism to ensure that RFMO's participants fully comply with the terms of their agreement. The mechanism is that RFMO participants finance and empower an independent enforcement body that possesses monitoring and sanctioning capabilities. We have demonstrated that if the cost of enforcement is not too high, and a minimum fine for non-compliance behaviour is applied, a non-cooperative solution is not the inevitable outcome when three or more countries are sharing a fishery. In addition, at some participant's enforcement cost level, when it increases, an RFMO will either requires a greater membership to enter into force or may not be worthwhile at all. As a result, if an RFMO forms, it not only leads to the higher cooperation level associated with higher steady-state fish stock but also may improve participant's rent. Specifically, when no more than four countries are involved in a shared fishery and $0 < T \le \pi(1) - \pi(0)$, this mechanism can lead to stable full cooperation. Furthermore, when five countries or more are sharing a fishery, a partial stable cooperation will exists under a certain condition of the participant's enforcement cost. Finally, the costly enforcement mechanism in which T reaches the upper limit of $\pi_p(\frac{N-1}{N}) - \pi(0)$ leads to not only stable full cooperation associated with the highest level of steady-state fish stock, but also the highest level of participant's rent.

Within a Cournot game, according to present research, firstly an increase in cooperation level is a social welfare improvement. Secondly, the perspective for cooperation in shared fisheries is optimistic if an RFMO with effective enforcement is established. Thirdly, a self-financed enforcement mechanism may be a solution for the protection of cooperation. This proposes that under certain conditions of enforcement cost, it is still rational to establish an RFMO to manage a shared fishery, even if not all the countries involved ratify the UNFSA, or the IUU problem may arise when five countries or more are sharing a fishery. Fourth, in some cases, an increase in participant's enforcement cost requires a higher minimum participation level for the existence of an RFMO. If an RFMO establishes, it not only results in the higher cooperation level associated with higher steady-state fish stock but also may improve participant's rent. Future studies may consider other enforcement cost structures. Heterogeneous unit effort cost, catchability coefficient, and unit harvest price of various countries sharing a fishery, should also be examined. Case examination of more complex specifications of the rent, cost and harvest functions, and dynamic analysis, may also be natural extensions of the present research.

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ANNEXES

Annex 0: Proofs of Maximization Problems

$(3) \Leftrightarrow \pi_{np} = A(1-b)e_{np} - \frac{Aq}{r}\left([N(1-s)-1]\bar{e}_{np} + \bar{E}_p\right)e_{np} - \frac{Aq}{r}e_{np}^2$, where $A=pqK$. Taking the first derivative, we have $e_{np} = \frac{r(1-b)}{q[N(1-s)+1]} - \frac{\bar{E}_p}{[N(1-s)+1]}$, namely (3').

$(4) \Leftrightarrow P_p = A(1-b)E_p - \frac{Aq}{r}[N(1-s)\bar{e}_{np}]E_p - \frac{Aq}{r}E_p^2$. Taking the first derivative, $E_p = \frac{r(1-b)}{2q} - \frac{1}{2}N(1-s)\bar{e}_{np}$, namely (4'). From (3') and (4') we have $E_p = e_{np} = \frac{r(1-b)}{q[N(1-s)+2]} \Rightarrow e_p = \frac{r(1-b)}{qNs[N(1-s)+2]}$. Therefore,

$E = E_p + N(1-s)e_{np} = \frac{r(1-b)[N(1-s)+1]}{q[N(1-s)+2]}$. We have:

Steady-state fish stock: $x = K - K\frac{q}{r}E = K\left[1 - \frac{N(1-s)+1}{N(1-s)+2}(1-b)\right]$

Rent of a participant:

$$\pi_p = pqe_p x - ce_p = rpKe_p\left[1 - \frac{N(1-s)+1}{N(1-s)+2}(1-b) - b\right] = rpK(1-b)e_p\frac{1}{N(1-s)+2} = \frac{rpK(1-b)^2}{Ns[N(1-s)+2]^2} = \frac{4\prod(1)}{Ns[N(1-s)+2]^2}$$

Resouce rent of a non - participant :

$$\pi_{np} = pqe_{np}x - ce_{np} = pqKe_{np}\left[1 - \frac{N(1-s)+1}{N(1-s)+2}(1-b) - b\right] = pqK(1-b)e_{np}\frac{1}{N(1-s)+2}$$

Since $e_{np} = \frac{r(1-b)}{q[N(1-s)+2]}$, thus $\pi_{np} = \frac{rpK(1-b)^2}{[N(1-s)+2]^2} = \frac{4\prod(1)}{[N(1-s)+2]^2}$

Total rent of the fishery :

$$\prod = Ns\pi_p + N(1-s)\pi_{np} = rpK(1-b)^2\left[\frac{N(1-s)+1}{[N(1-s)+2]^2}\right] = 4\left[\frac{N(1-s)+1}{[N(1-s)+2]^2}\right]\prod(1)$$

Annex 1: Proofs of Proposition 1

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

Since $\frac{N(1-s)}{N(1-s)+1} > \frac{N(1-s)+1}{N(1-s)+2} \Rightarrow x(s) < x(s+\frac{1}{N})$.

$\prod(s) = 4\left[\frac{N(1-s)+1}{[N(1-s)+2]^2}\right]\prod(1)$ and $\prod(s+\frac{1}{N}) = 4\left[\frac{N(1-s)}{[N(1-s)+1]^2}\right]\prod(1) \Rightarrow \prod(s) < \prod(s+\frac{1}{N})$.

$\pi_p(s) = \frac{4\prod(1)}{Ns[N(1-s)+2]^2}$ in $\left[\frac{2}{N}, \frac{N-1}{N}\right]$, we have $s \in \left[\frac{2}{N}, \frac{N+2}{3N}\right], \frac{\partial \pi_p}{\partial s} \le 0$ and $s \in \left[\frac{N+2}{3N}, \frac{N-1}{N}\right], \frac{\partial \pi_p}{\partial s} \ge 0$. It is also easy to prove that $\pi(0) > \pi_p(s = \frac{2}{N})$ and $\pi(1) > \pi_p(s = \frac{N-1}{N})$.

Annex 2: Proofs of Proposition 2

2.1. From Proposition 1.3 and, $\pi_p(\frac{N-1}{N}) < \pi(0) \Leftrightarrow (N-2)(N-5) < 0 \Rightarrow N < 5$

2.2 $N \geq 5 \Rightarrow \pi_p(\frac{N-1}{N}) \geq \pi(0)$

Annex 3: Proofs of Proposition 3

Firstly, from (9) $s^{nc} = \min s|\pi_p(s) - \pi(0) \geq 0$ and Proposition 1.3, we have $s^{nc} > \frac{N+2}{3N}$. Moreover,

$\frac{\partial \pi_p(s)}{\partial s} = \frac{4(3Ns - N - 2)\prod(1)}{Ns^2[N(1-s)+2]^3} > 0$ and $\frac{\partial^2 \pi_p(s)}{\partial s^2} > 0 \ \forall s \in [s^{nc}, 1]$. Therefore,

$$\pi_p(s^{nc}) - \pi(0) < \pi_p(s) - \pi_p(s-1/N) \Rightarrow \pi_p(s-1/N) - \pi(0) < \pi_p(s) - \pi_p(s^{nc}) \quad (13)$$

$$\pi_p(s-1/N) - \pi_p(s-2/N) < \pi_p(s) - \pi_p(s-1/N) \Rightarrow \pi_p(s-1/N) - \pi(0) < \pi_p(s) - \{\pi_p(s-1/N) - [\pi_p(s-2/N) - \pi(0)]\} \quad (14)$$

Secondly, from (11) $s^c = \min s|\pi_p(s) - T - \pi(0) \geq 0$ and $T > 0$, therefore $s^c \geq s^{nc}$.

3.1. $0 < T \leq \pi_p(s^{nc}) - \pi(0) \Rightarrow T_{\max} = \pi_p(s^{nc}) - \pi(0)$. Therefore:

$$s^c = \min s|\pi_p(s) - (\pi_p(s^{nc}) - \pi(0)) - \pi(0) \geq 0 \Leftrightarrow s^c = \min s|\pi_p(s) - \pi_p(s^{nc}) \geq 0 \Rightarrow s^c = s^{nc}$$

3.2. From $\pi_p(s^c - 1/N) - \pi(0) < T \leq \pi_p(s^c) - \pi(0) \Rightarrow T_{\max} = \pi_p(s^c) - \pi(0)$, this clearly satisfies (11). Thus a stable coalition always exists at the level of cooperation s^c. Furthermore, in the case of costless enforcement, participant's rent is $\pi_p(s^{nc})$. In the costly enforcement, at the stable cooperation level of s^c it is $\pi_p(s^c) - T$. Hence, if $\pi_p(s^c) - T \geq \pi_p(s^{nc}) \Rightarrow \pi_p(s^c - 1/N) - \pi(0) < T \leq \pi_p(s^c) - \pi_p(s^{nc})$, participant's rent is at least as large as that of the costless enforcement case. Clearly (13) shows that there exists *T* to satisfy this condition.

3.3. When $\pi_p(s-2/N) - \pi(0) < T \leq \pi_p(s-1/N) - \pi(0)$, a stable coalition exists at the level of cooperation $s^c = s - 1/N$. Therefore its maximum participant's rent is smaller than $\pi_p(s-1/N) - [\pi_p(s-2/N) - \pi(0)]$. Thus, $\pi_p(s) - \{\pi_p(s-1/N) - [\pi_p(s-2/N) - \pi(0)]\} < \pi_p(s) - \pi(0)$.

Next, Proposition 3.2 shows that when $\pi_p(s-1/N) - \pi(0) < T \leq \pi_p(s) - \pi(0)$, a stable coalition exits at the level of cooperation $s^c = s$. Thus, if $\pi_p(s-1/N) - \pi(0) < T \leq \pi_p(s) - \{\pi_p(s-1/N) - [\pi_p(s-2/N) - \pi(0)]\}$, a stable cooperation will exists at the level of $s^c = s$ and participant's rent is always higher than at $s^c = s - 1/N$. Clearly, (14) shows that there exists *T* to satisfy this condition.

3.4. When $T > \pi(1) - \pi(0) \Rightarrow \pi(1) - T < \pi(0)$, it is not rational that the RFMO should exist.