Zonal Attachment of Fish Stocks and Management Cooperation

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Abstract

This paper studies the incentive-compatibility of distributing fish quotas on the basis of zonal attachment of stocks. Two countries sharing two fish stocks are studied, with the zonal attachment of both stocks varying randomly. The base case is one of symmetric stocks, where one country is the dominant player for one stock. While each country has weak or no incentive to cooperative on the stock in which it holds only a minor share, both countries would have incentives to cooperate on both stocks if they are jointly managed. If one country is the major player with respect to both stocks, the minor player has weak or no incentive to cooperate. The incentive to cooperate is not any stronger if the variations in the zonal attachment of the two stocks are negatively correlated.

Keywords: zonal attachment, game theory, fisheries management, fish quotas.

1. INTRODUCTION

Management of fish stocks that migrate between the economic zones of different countries is a thorny issue, particularly when these migrations change in unforeseen ways. Migrations between national economic zones and the high seas (areas outside any country's exclusive economic zone) pose similar and even more serious problems, since no single country has jurisdiction over fisheries in those areas.

"Zonal attachment" is a concept that has been applied in the management of shared stocks between the European Union and Norway (Engesæter, 1993, and Hamre, 1993). Briefly, this works as follows. "Zonal attachment" of a stock is the share of the stock residing within a particular country's economic zone, if necessary weighted by the time it spends in a country's zone over a year. This, then, determines the share that each country gets of the total catch quota for that stock. In the early 1980s the zonal attachment of various fish stocks shared by Norway and the European Union was determined. The share parameters emerging from this work have since been applied for several stocks shared by the two entities. This has been unproblematic, except for the North Sea herring. In the early 1980s this stock had been severely depleted and was subject to a moratorium on fishing. At that time, most of what was left of the stock resided in the EU-zone. When the fishery was opened in 1985 the EU offered Norway a 4 percent share of the total catch quota, based on the zonal attachment of the stock in the early 1980s. Norway refused the offer, arguing that a larger part of a now recovered stock was in the Norwegian zone. The dispute was resolved after a year, and Norway has for many years got 29 percent of the overall catch quota.

For other migratory stocks involving Norway and her neighbors there have been similar disputes. The agreement on Norwegian spring spawning herring, a stock that migrates between the Norwegian and Icelandic economic zones, was defunct for several years around the turn of the century because of a disagreement over the division of the catch quota. In 2008 the Atlantic mackerel began to show up in the Icelandic economic zone in large quantities, leading to disagreement on the division of the overall catch quota that has not yet (December 2012) been resolved. In the 1990s a similar dispute broke out between the United States and Canada over distribution of salmon catches, caused by an unforeseen and radical change in the migration runs of Pacific salmon (Miller and Munro, 2004).

With the division of catch quotas based on zonal attachment of fish stocks, it is unsurprising that changes in fish migrations lead to a breakdown of existing agreements. But the problems surrounding the zonal attachment as a basis for the division of overall fish quotas do not end there. One may ask whether zonal attachment is at all a suitable criterion to divide up fish quotas. The answer is “not necessarily”, as discussed by Hannesson (2006, 2007) in the context of a given zonal attachment. The purpose of this paper is to extend the analysis to the cases where the zonal attachment varies over time and more than one stock is involved. The formal analysis is limited to two stocks shared between two countries, with the zonal attachment of both stocks varying over time. Would it promote cooperation if both were managed jointly, with the countries considering the outcome of cooperation or its opposite for both stocks in the aggregate? How much does it matter whether one country is a dominant player for one stock or for both jointly? Is negative correlation between the variations in the zonal attachment of the stocks important? One might think so, as a loss with respect to one stock might be compensated by a gain for the other, making cooperation more attractive.

The approach is standard in game theory. We derive the payoff that would be obtained in a Nash equilibrium where each country maximizes its own present value of profits, given what the other country does. If fish quota distribution on the basis of zonal attachment is viable, it must give each country a payoff at least as large as obtained in the Nash equilibrium.

The model used is numerical, which is necessary for simulation purposes, but otherwise fairly general. We consider fish stocks capable of yielding some surplus growth with stock levels below some maximum size, which may be identified as natural equilibrium in the absence of exploitation. The relative surplus growth rate is diminishing in the stock. The surplus growth in any given period depends on the stock that was left after fishing in the previous period. The model is deterministic, except that the share of the stock that turns up in each country's waters at the beginning of each period (alias zonal attachment) varies stochastically. It is assumed that the fish turning up in each country's zone stay there during the fishing period, but after that the stock grows and breeds as a unit. The two stocks we consider are identical, except for their distribution between the economic zones of the two countries.

2. THE MODEL

As the two stocks to be considered are identical except for their zonal distribution, we describe the generic stock model. Denoting the stock at the beginning of year t as X_t, the stock in Country 1's zone will be $\alpha_t X_t$, and stock in Country 2's zone $(1 - \alpha_t)X_t$, with α_t being the share of the stock turning up in Country 1's zone.

Once the stock has appeared in each country's zone it stays there until the end of fishing. Country i chooses the stock level S_i to leave behind in its own zone. After fishing the stock intermingles and grows and reenters the two zones, with a new distribution determined by α_{t+1}. We shall use the following growth function

(1) $$X_{t+1} = \left(S_{1t} + S_{2t}\right)\left[1 + a\left(1 - S_{1t} - S_{2t}\right)\right]$$

In this formulation, the carrying capacity of the environment is implicitly set at 1, with a stock between 0 and 1 yielding a positive surplus growth. The marginal growth rate of the stock is decreasing in S ($\frac{\partial X}{\partial S} = 1 + a\left(1 - 2S\right)$).

For a constant price of fish (p), the revenue from fishing in Country 1 is $p\left(\alpha_t X_t - S_{1t}\right)$, the value of the difference between the initial stock in Country 1's zone and the stock left behind by Country 1 (for Country 2, substitute $1 - \alpha$ for α). For simplicity, stock growth and fishing are regarded as two processes separate in time, with fishing taking place first.

Costs are more complicated. We shall assume that the instantaneous catch of fish is proportional to fishing effort (Z). With c being the cost per unit of fishing effort, the cost per unit of fish caught will be $cZ/Zs = c/s$, where s is the size of the stock being fished and Z suitably defined to give a catchability coefficient of 1. This implies that the stock is always evenly distributed over a given area where the effort is applied at random, so that its density is proportional to its abundance. From this we get the cost function

$$(2) \qquad C = -\int_X^S \frac{c}{s} ds = c\left[\ln X - \ln S\right]$$

The assumption that the stock distributes itself over the economic zones of two countries, which may or may not be adjacent, introduces complications. We make the assumption that the size of the area which the stock occupies in each country's zone is proportional to the share parameters α and $1 - \alpha$. This implies that the density of the stock is the same in the economic zones of both countries at the beginning of the fishing period and proportional to X. In the absence of management, the stock would be fished down over the fishing period to the critical density where further fishing would be unprofitable. If the entire stock is in one country's zone this critical density would correspond to an amount $S^* = c$ of fish. In the zone with the share α of the stock the amount of fish at this density would be αS^*. Hence we multiply the cost parameter c in Equation (2) by α versus $1 - \alpha$. So, with Country 1 leaving behind αS^* fish in its zone and Country 2 $(1 - \alpha)S^*$ in its zone, the total amount left would be S^*, just as if the stock were distributed over a single homogeneous area.

With this adjustment, the cost per unit of fish caught in Country 1's zone will be $\alpha cZ/Zs$ = $\alpha c/s$. The cost function for Country 1 becomes

$$(2') \qquad C = -\int_{\alpha X}^{S} \frac{\alpha c}{s} ds = \alpha c\left[\ln \alpha X - \ln S\right]$$

and analogous for Country 2.

The chosen formulation has the advantage that the density of the initial stock is always the same for any given initial size (X), irrespective of how it is distributed between the two countries' zones. The profit from considering the stock as one unit will then be the same as the aggregate profit if the stock density after fishing is the same in both countries' zone. The aggregate profit from leaving behind stock S^* is

$$(3) \qquad \pi = p\left(X - S^*\right) - c\left[\ln X - \ln S^*\right]$$

The aggregate profit from leaving behind S_1 and S_2 in the two countries' zone is

(3')

$$\pi_1 + \pi_2 = p\left(\alpha X + (1-\alpha)X - S_1 - S_2\right) - \alpha c\left[\ln \alpha X - \ln S_1\right] - (1-\alpha)c\left[\ln(1-\alpha)X - \ln S_2\right]$$

If $S_1 = \alpha S^*$ and $S_2 = (1 - \alpha)S^*$, this is equal to π.

The optimal solution

The growth function implies that the stock left after fishing in period t affects the returning stock in period t+1, but not the stock in later periods. At the beginning of each period a decision will be made about how much fish to leave behind. As long as economic parameters and expectations about the future remain the same these decisions will be identical in all periods. We can find the optimal stock in period t either by maximizing the present value of profits over two adjacent periods, for a given initial stock, or by finding the optimal stock emerging after the first period and maximizing the present value of the fishery over an infinite horizon with identical subsequent periods. Both approaches give the same solution, but the former has the advantage that it also works for the case of a zero discount rate.

(4) Maximize (with respect to S_t)

$$V_t = p\left(X_t - S_t\right) - c\left[\ln X_t - \ln S_t\right] + \left(1+r\right)^{-1}\left\{p\left[X_{t+1}\left(S_t\right) - S_{t+1}\right] - c\left[\ln X_{t+1}\left(S_t\right) - \ln S_{t+1}\right]\right\}$$

Using the above growth equation (1) with $S_t = S_{1t} + S_{2t}$, we get the following first order condition:

(5)
$$-p + \frac{c}{S_t} + \left(1+r\right)^{-1}\left\{\left[p - \frac{c}{S_t\left(1+a\left(1-S_t\right)\right)}\right]\left(1+a\left(1-2S_t\right)\right)\right\} = 0$$

from which we can find the optimal S_t.

The Nash equilibrium

As usual, we define the Nash equilibrium as the profit-maximizing stock to be left behind by Country 1 after fishing, given the stock left behind by Country 2, and *vice versa*, and look at mutually consistent conjectures. This also involves optimizing over two adjacent periods. For Country 1 we get

(4') Maximize (with respect to S_{1t})

$$p\left(\alpha_t X_t - S_{1t}\right) - \alpha_t c\left(\ln \alpha_t X_t - \ln S_{1t}\right)$$
$$+\left(1+r\right)^{-1}\left\{p\left[\alpha_{t+1} X_{t+1}\left(S_{1t} + \bar{S}_{2t}\right) - S_{1t+1}\right] - \alpha_{t+1} c\left[\ln \alpha_{t+1} X_{t+1}\left(S_{1t} + \bar{S}_{2t}\right) - \ln S_{1t+1}\right]\right\}$$

and analogous for Country 2, with $1-\alpha$ substituted for α. A bar over a variable indicates that it is taken as given by the maximizing country. We get mutually consistent conjectures when $S_i^o = \bar{S}_i$ for both countries, with S_i^o denoting the optimal value for Country *i*.

At time *t* the value of α_{t+1} will certainly not be known, while α_t will either become known during period *t* or at best become known at the beginning of period *t*. Therefore, each country can use the current zonal attachment (α_t) in its optimization. If the zonal attachment of the stock varies in a truly random fashion, the countries involved will presumably be aware of this and hence substitute the expected value $\hat{\alpha}$ for α_{t+1}. Hence, the maximum condition for Country 1 is

(5’)

$$-p+\frac{\alpha_t c}{S_{1t}}+(1+r)^{-1}\hat{\alpha}\left[p-\frac{c}{\left(S_{1t}+\bar{S}_{2t}\right)\left(1+a\left(1-S_{1t}-\bar{S}_{2t}\right)\right)}\right]\left(1+a\left(1-2\left(S_{1t}+\bar{S}_{2t}\right)\right)\right)\leq 0$$

and analogous for Country 2. From this we can find Nash equilibrium S_{1t} and S_{2t}, which will vary over time because α_t varies over time. If (5’) holds with inequality, then $S_i = 0$.

3. SIMULATIONS

Since the cooperative solution explicitly maximizes joint profits it will necessarily be better than Nash equilibrium. The problem is to find a robust rule which will make it profitable for both countries to go for a cooperative solution rather than a Nash equilibrium. Would zonal attachment be such robust rule? Since zonal attachment varies stochastically the division of cooperative profits on its basis is not uniquely determined. Two possibilities come to mind: (i) division on the basis of actual zonal attachment (α_{t-1}), or (ii) division on the basis of expected zonal attachment ($\hat{\alpha}$). The reason for defining actual zonal attachment with reference to the previous period is that catch quotas will probably have to be set prior to the fishing season, and so the most up to date information that can be used is the zonal attachment in the previous period. Both of these will be considered in the following as needed to ascertain whether they would lead to different results.

It will be assumed that fishing takes place in a cost-minimizing way in the cooperative solution. This would entail that the two countries, if they cooperate, grant each other mutual access rights in each other's zone, so that the stock is fished in such a way that its density after fishing is the same in both zones.

The evaluation of the two strategies, Nash equilibrium versus profit sharing on the basis of zonal attachment, was made by running 30 simulations of the fishery over a time horizon of 20 years. Thirty simulations may sound like a small number, but the outcome is not very sensitive to increasing the number of simulations. The problem of a short time horizon is avoided by setting the discount rate equal to zero, which in effect amounts to maximizing sustainable economic yield (it may be noted that adding years under these circumstances is equivalent to running more simulations). As is well known, time discounting could make it more difficult to cooperate on shared fish stocks, but this is not the problem we want to focus on in this paper.

The basic equation for variable zonal attachment is

$$(6) \qquad \alpha_t = \alpha_{\min} + \varepsilon_t \left(1 - \alpha_{\min}\right)$$

where $\alpha_{\min}$ is the minimum share of the stock always going to one particular country's zone and ε is an evenly distributed random variable between 0 and 1. With $\alpha_{\min} > 0$, one country will be the dominant player, in the sense of getting a larger share of the stock on the average. With $\alpha_{\min} > 0.5$, one country will always receive a larger share of the stock than the other. With $\alpha_{\min} = 0$ both countries are equal, and the share of the stock in each country's zone is entirely random. With two stocks and two countries involved, one country could dominate with respect to both stocks or just one.

In the next section, results for five cases will be presented:

(i) Symmetry of countries and stocks, focusing on the outcome of exploiting the minor stock. In this case both stocks have the same $\alpha_{\min}$ (but different drawings of ε_t), and Country 1 dominates with respect to Stock 1 and Country 2 with respect to Stock 2. We consider one country and its payoff from the minor stock, that is, the country has share parameter $1 - \alpha_t$, as defined by Equation (1). Would the country be better off by cooperating with respect to this particular stock?

(ii) Symmetry of countries and stocks, focusing on the major stock. This is the same as (i), except that the country has share parameter α_t, as defined by Equation (1). Would the country benefit from cooperating with respect to this stock only?

(iii) Symmetry of countries and stocks, considering cooperation with respect to both stocks jointly. We consider the joint payoff of one country from the major and the minor stock, but because of the symmetry between countries and stocks the outcome for the other country is essentially the same (the numbers might differ slightly because of the randomness in the zonal attachment).

(iv) Asymmetry where one country has on average a larger share of both stocks, not necessarily equal for both. How would this affect the incentives to cooperate for both countries?

(v) The zonal attachments of the two stocks are negatively correlated. The presumption is that this would improve the prospect of cooperation, as one stock would be relatively plentiful when the other is less so, providing a greater scope for give and take. The correlation is modeled as follows:

(6'a) $$\alpha_{i,1} = \alpha_{\min,1} + \left(1 - \alpha_{\min,1}\right)\varepsilon_1$$

(6'b) $$\alpha_{i,2} = \alpha_{\min,2} + \left(1 - \alpha_{\min,2}\right)\left(\beta\varepsilon_2 + \left(1-\beta\right)\left(1-\varepsilon_1\right)\right)$$

where the ε's are evenly distributed random variables between 0 and 1. Thus, for Stock 2, the zonal attachment is negatively influenced by the random events that govern the zonal distribution of Stock 1, unless $\beta = 1$. If $\beta = 0$ the variations in the zonal attachment of Stock 2 are exactly the opposite of the variations for Stock 1.

4. RESULTS

(i) Symmetry of countries and stocks, results from cooperation with respect to the minor stock

As described in the preceding section, the zonal attachment of the two stocks varies in a symmetric fashion; that is, $\alpha_{\min}$ is the same for both stocks, and both vary according to a random variable, but with different draws for the two stocks. The countries are also symmetric, with one country having (on the average when $0 < \alpha_{\min} < 0.5$) the major share of one stock.

Figure 1 shows the difference (average of all simulations) between the cooperative profit and the Nash equilibrium profit from the minor stock for one country, for the two divisions of the cooperative profit discussed in the previous section, one based on average zonal attachment (fixed share) and the other on zonal attachment in the previous period (variable share). With $\alpha_{\min} = 0$ the stock is in effect not a minor stock for either country, but as $\alpha_{\min}$ increases the stock tends to be more strongly attached to the other country, as this parameter shows the minimum share of the stock that will always go the zone of that country. With $\alpha_{\min} < 0.5$ that country will not necessarily get more than a half of the stock, but on the average it will, so there is justification for calling it the major stock for that country. We see that for $\alpha_{\min} \geq 0.3$

the cooperative solution becomes unattractive for the minor player, the one that on average gets a smaller share of the stock.

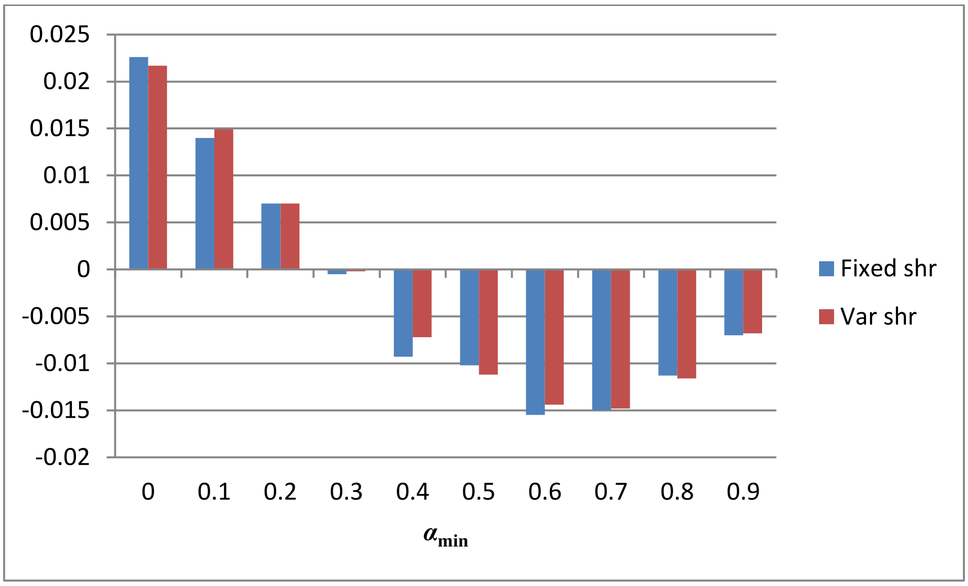

Figure 1: Average difference between the cooperative profit and the Nash equilibrium profit from the minor stock, with division of profit based on average zonal attachment (fixed share) versus zonal attachment in the previous period (variable share). Parameter values: p = 1, a = 1, c = 0.2.

(ii) Symmetry of countries and stocks, results from cooperation with respect to the major stock

Figure 2 shows the difference between the cooperative and non-cooperative profit for one country for the major stock, both on average for all simulations as well as maximum and minimum. On average the country always gains, but the opposite may happen; there is one such simulation with α_{min} = 0.5.

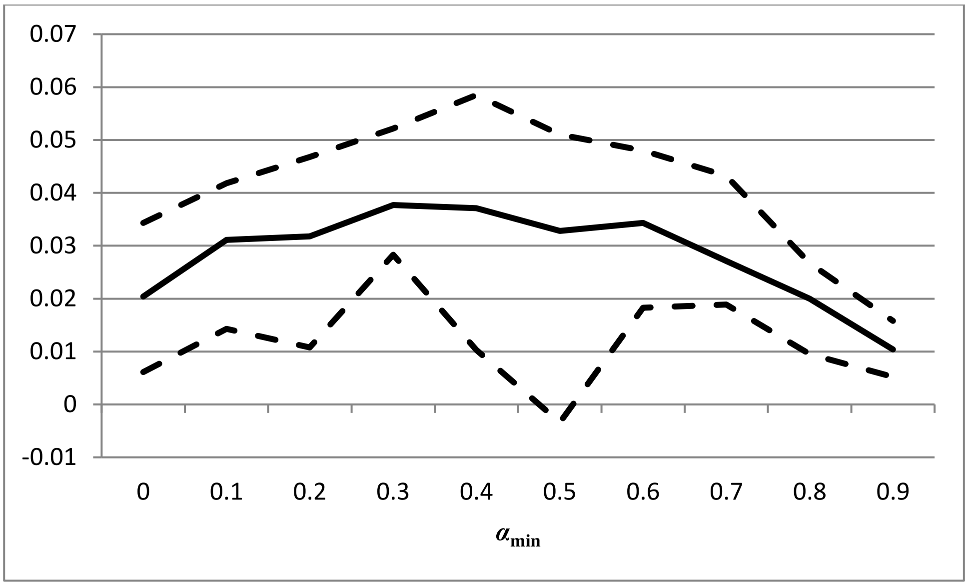

Figure 2: Average, maximum and minimum difference between the cooperative profit (fixed zonal attachment) and the non-cooperative profit from the major stock in one country. Parameter values: p = 1, a = 1, c = 0.2.

(iii) Symmetry of countries and stocks, cooperation on both stocks jointly

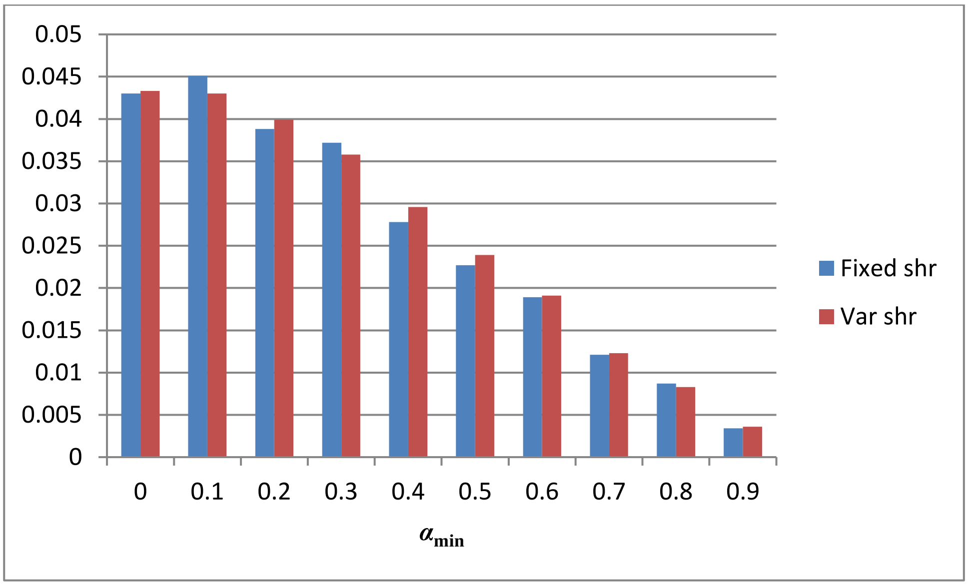

Figure 3: Difference between the cooperative profit and the Nash equilibrium profit for one country when both the major and the minor stock are considered jointly. Parameter values: p = 1, a = 1, c = 0.2.

Figure 3 shows the difference (average from all simulations) between the cooperative profit and the Nash equilibrium profit for one country when both the major and the minor stock are considered jointly. In all cases this difference is positive; what the country loses from abstaining from fishing its minor stock heavily is more than made up for with greater profits from the major stock. Even when most of the major stock always resides in one country's zone and the minor country could only do limited damage with its aggressive fishing (α_{min} = 0.9), there is still some gain to be had from cooperation. We thus have a case where considering both stocks jointly improves the attractiveness of the cooperative solution so that it is preferable to the non-cooperative one. Country 2, which is a minor player with respect to Stock 1, would lose from cooperating on that stock only, but would gain from doing so if it entices Country 1, which is the minor player with respect to Stock 2, to cooperate on Stock 2. The same applies to Country 1 and Stock 2.

The difference between the outcomes for a fixed versus a variable share of the cooperative profit is negligible in all cases, both when we consider the minor stock in one country (Figure 1) and the outcome for both stocks jointly (Figure 3). The results are not very sensitive to changing the stock growth parameter (a); for lower a, it takes a slightly higher α_{min} to make the cooperative solution unattractive for the minor stock. This harks back to a result obtained by Mesterton-Gibbons to the effect that it is easier to obtain cooperation on a common resource the less productive it is (Mesterton-Gibbons, 1993). Neither are they sensitive to changing the cost parameter (c), but for high values ($c \geq 0.8$) the difference between the cooperative solution and the non-cooperative one becomes negligible.

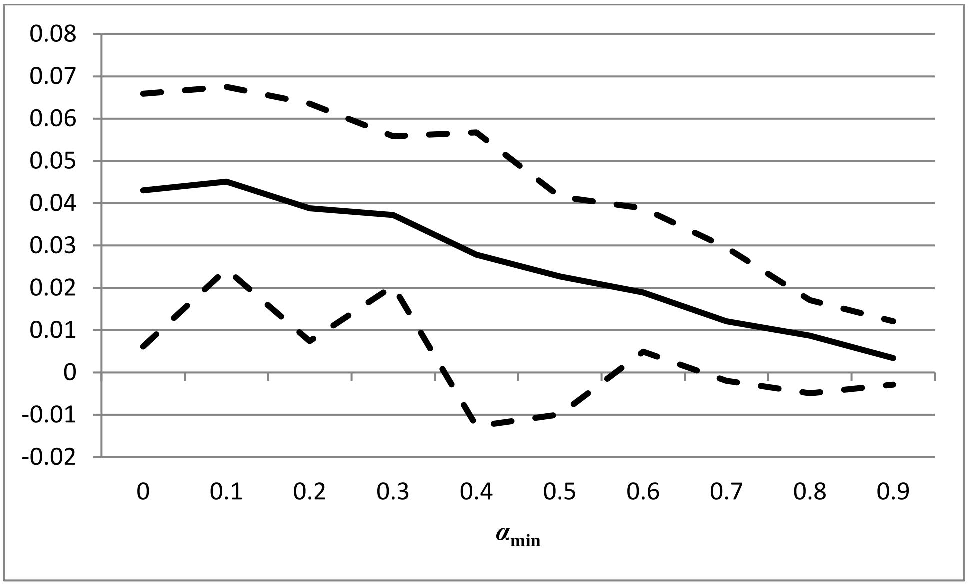

Figure 4: Average, maximum and minimum difference between cooperative profit (fixed zonal attachment) and the non-cooperative profit for both stocks jointly. Parameter values: p = 1, a = 1, c = 0.2.

Figures 4 is similar to Figure 2 and shows the difference between the cooperative and non-cooperative profit for one country for both stocks jointly, both on average for all simulations as well as maximum and minimum. We see that non-cooperation can be better in some simulations than cooperation when the minor country's share in the stock is sufficiently small ($\alpha_{\min} > 0.3$).

(iv) Asymmetric countries

Here the countries are asymmetric, with one country having a larger average share of both stocks. Figure 5 shows the difference between the cooperative and non-cooperative profits from both stocks jointly for the two countries (fixed shares; average for all simulations). While the dominant country would always benefit from the cooperative solution, the minor country would not, unless there is a small enough difference between the average zonal attachment for the two countries ($\alpha_{\min} < 0.3$). Note that $\alpha_{\min}$ here means the minimum share of both stocks that will go into the major player's zone.

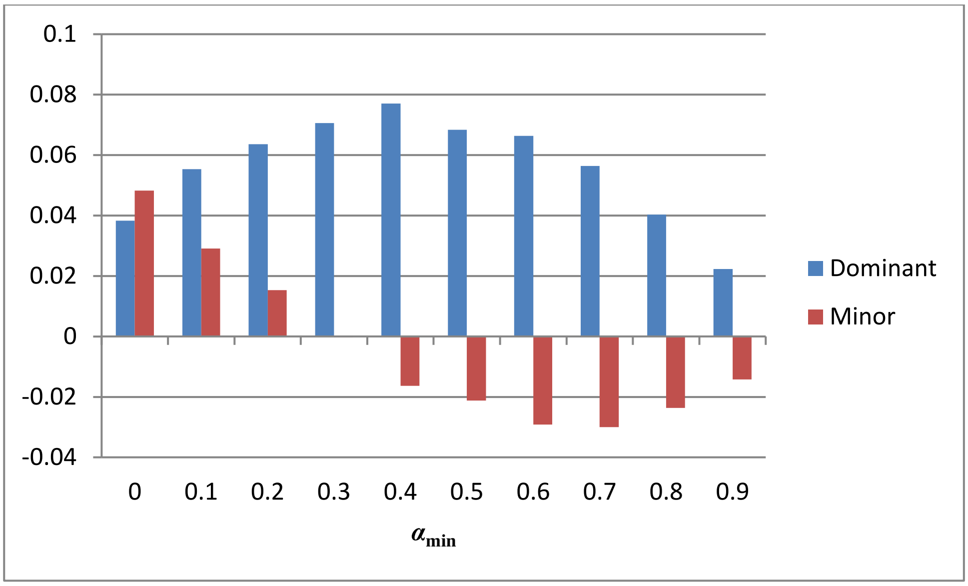

Figure 5: Asymmetric countries. Difference between cooperative and non-cooperative profit (constant zonal share) from both stock jointly. Parameter values p = 1, a = 1, c = 0.2.

What if the minimum share of the stock in the dominant country's zone is different for the two stocks? Suppose, for example, that $\alpha_{\min} = 0.4$ for one stock, and let it vary for the other. It turns out that the minor player would not gain on the average from adhering to the cooperative solution for both stocks if $\alpha_{\min} > 0.3$ for the other stock. The result is fairly robust to changing the rate of growth (a) and the cost (c) parameters, but the lower the rate of growth the higher is the $\alpha_{\min}$ which causes the non-cooperative solution to be preferable. This is yet another example where cooperation is made more likely the less there is at stake; a lower rate of growth makes the stock less productive, and the higher the $\alpha_{\min}$ the less there will be of the stock in the minor player's zone.

(v) Negative correlation in zonal attachment

Figure 6 shows how the difference (average for all simulations) between the cooperative and non-cooperative profit for both stocks jointly, for the country with a smaller share of both stocks, varies with the parameter β, explained in the previous section. For both stocks $\alpha_{\min}$ = 0.3. Figure 6 shows that the cooperative solution for both stocks jointly is slightly inferior for the minor player with $\beta = 1$, in which case the zonal attachments of the two stocks are uncorrelated. The result is virtually the same as in Figure 5, but difficult to see because of the different scales on the y-axis in the two figures. From Figure 6 we see that a negative correlation between the stocks ($\beta < 1$) does nothing to make the cooperative solution more attractive; for all values of β the non-cooperative solution is slightly better than the cooperative one, and the difference is not much affected by the (negative) correlation between the zonal attachment of the two stocks (note again the scale of the y-axis in Figure 6). The result is robust to changes in the parameters a and c; the difference between the cooperative and the non-cooperative solution is little affected, but with a lower growth rate it takes a higher α_{min} to make the jointly cooperative solution unattractive for the minor player, just as in the absence of correlation (case iv above).

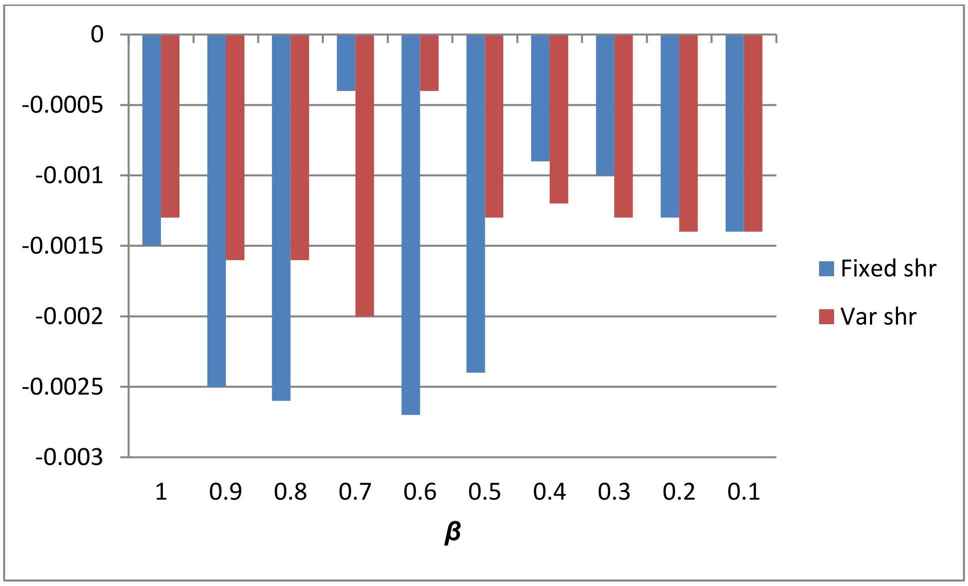

Figure 6: The difference between the cooperative and non-cooperative profit for the country with a smaller share of both stocks ($\alpha_{1,min} = \alpha_{2,min} = 0.3$). Parameter values $p = 1$, $a = 1$, $c = 0.2$.

5. CONCLUSION

We have seen that countries could gain from a joint management of fish stocks with a variable zonal attachment. This is not primarily due to the variability in the migrations (zonal attachment) of the stocks, but is mainly caused by countries having a dominant interest in different stocks. In the two-stocks-two-countries model at hand, this happens because each country is a dominant player for one stock. Each country has primarily an incentive to conserve the stock for which it is a dominant player, but the result can be improved by getting the country with a minor interest to play along. Both can benefit from mutual exchange; Country 1, with a dominant interest in Stock 1, would primarily benefit if Country 2 accepts to cooperate about Stock 1, which it will not do if it is against its interests, but could be enticed to do so if Country 1 also cooperates on the management of Stock 2, in which it has only a minor interest. In this way, mutual cooperation on different stocks can be in everyone's interest, even if cooperation on some stocks in isolation would not be. But note the requirement that both countries have a major interest in one of the stocks.

When one country has a major interest in both stocks, the incentive for the minor country to cooperate breaks down. This happens even if the country with a minor interest sometimes gets more than a half of the stock into its zone ($\alpha_{\min} < 0.5$). The lack of incentive to cooperate is embedded in having a minor interest in a stock, and variability in zonal attachment does little to strengthen the incentive to cooperate if a country has on average a minor interest in both stocks. Neither does a negative correlation between the zonal attachments of the two stocks. The overall conclusion, then, is that cooperation on shared stocks based on zonal attachment is most likely to result between countries that have a dominant interest in different stocks and not when some countries hold only a minor interest in all stocks. Cooperation can still be obtained, but in that case probably through providing the minor players with more generous shares of fish quotas than the zonal attachment would prescribe.

These results largely confirm the results in Hannesson (2006, 2007) where stock sharing on the basis of zonal attachment was shown as likely to be unacceptable, because it would give the player with a minor interest a worse outcome than he would get by pursuing his own interest in the absence of cooperation. But this paper has also shown that the scope of cooperation is greater if countries share more than one stock. For this to happen, each country has to be a dominant player with respect to one stock. If a country is a minor player for both stocks we only have an extended version of the minor player problem.

These results have empirical implications. The paper was inspired by the ongoing conflict between Norway and the EU on the one hand and Iceland and the Faeroe Islands on the other over the Northeast Atlantic mackerel (further on this, see Hannesson, 2012). As has often been pointed out, the countries involved share several stocks (herring and blue whiting, besides mackerel), all of which fluctuate over time in ways that seem largely uncorrelated. The idea has been put forward that it ought to be easier to agree on sharing these stocks if all of them were considered jointly. What this paper has shown is that this is not necessarily the case. The problem is that the Faeroe Islands and Iceland are minor players with respect to all of these stocks, and in that case agreement will not necessarily be any easier when considering all of them jointly.

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