Working Paper No. 15/04

Incentive Compatibility of Fish-Sharing Agreements

by

Rögnvaldur Hannesson

SNF-project No. 5015
"Economic Impact of Climate Change on Norway's Fisheries"
The project is financed by the Research Council of Norway

Centre for Fisheries Economics
Discussion paper No. 5/2004

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, APRIL 2004

ISSN 1503-2140

Incentive Compatibility of Fish-Sharing Agreements

Abstract

This paper discusses the incentive compatibility of fish-sharing agreements based on zonal attachment of fish stocks. It is shown that the minor partner in a fish-sharing agreement may not have an incentive to cooperate unless he gets a larger share of the cooperative profits than his share of the stock according to the zonal attachment. This is particularly likely to happen when the unit cost of fish does not depend on the stock.

INTRODUCTION

When the 200-mile economic zone became established in the 1970s, fish stocks that migrate across national boundaries became in effect the shared property of two or more countries. Successful management of such “transboundary” stocks requires that the countries involved agree on how they are to be shared and managed. In the late 1970s Norway and the European Union agreed to share seven transboundary stocks in the North Sea according to the “zonal attachment” of each stock.[1] The stocks are managed by setting an overall catch quota, which is then divided between Norway and the European Union as determined by the zonal attachment.

Zonal attachment can be defined and measured in various ways, and precisely how this is done can be controversial. Some fish may be spawned in the economic zone of one country while not becoming fishable until they have moved into the zone of another. Other types of fish may feed in the zone of one country but fishable mainly in the zone of another. In the agreements between the European Union and Norway zonal attachment was based on the presence of the fishable part of the stocks in each party’s zone in the years 1974-78 (Engesæter [1993], p. 94). In other contexts different approaches have been applied. One such uses biomass multiplied by the time migrating stocks spend in each country’s zone (Hamre [1993]). This was applied in the sharing of the capelin stock that migrates between the zones of Greenland, Iceland, and Jan Mayen, an island under Norwegian sovereignty (Engesæter [1993]). Instead of biomass this approach could be based on the growth of the stock (Hamre [1993]).

With the exception of North Sea herring, the sharing agreement for the North Sea stocks has held up well. Like other herring stocks, the North Sea herring stock fluctuates considerably in size because of environmental factors, and it changes its migratory behavior as it becomes more abundant. When the stock recovered in the 1980s from the breakdown in the 1970s it started to migrate further north and to a greater extent into the Norwegian exclusive economic zone. This made Norway unhappy with the 4 percent share she was being offered on the basis of the previous zonal attachment of the stock. For some time no agreement was in force, and Norway fished the stock at will within its own zone after the herring moratorium was lifted in 1984. In 1986 a new agreement was concluded giving Norway a share of 25, 29 or 32 percent, depending on the size of the spawning stock (Engesæter [1993], p. 96), the more the larger the stock is.

There have been other and less successful attempts to apply the zonal attachment principle. No agreement has yet been obtained for blue whiting and mackerel in the Northeast Atlantic, and an agreement on sharing the Norwegian spring spawning herring recently fell through. A complicating factor is that these stocks migrate into the high seas outside the exclusive economic zone of any country where no single country has jurisdiction and international agreements are difficult to enforce. But there are other problems with the zonal attachment principle. It may appear reasonable and fair, but there is no a priori reason why it should be compatible with the incentives of the individual parties. In this paper it is shown that countries with a minor share in a stock could be better off by exploiting the fish in their own zone as they best see fit than by cooperating on the basis of the zonal attachment principle. This is particularly likely to happen for stocks where the unit cost of fish is only weakly related to the size of the exploited stock. This apparently is the case for the said stocks for which no

[1] These stocks are cod, haddock, saithe, plaice, whiting, sprat and herring (Engesæter [1993]). On the concept of zonal attachment, see ICES (1978) and Engesæter (1993).

agreement is in force.[2] These incentive problems could be the reason, rather than the fact that the stocks involved are accessible on the international high seas. What is perhaps more surprising is that the sharing agreements for the stocks in the North Sea have held up so well despite being based on the principle of zonal attachment.

In this paper it will be assumed that the zonal attachment of fish stocks is constant and independent of how intensively they are exploited. This is probably the case most favorable for the incentive compatibility of the zonal attachment principle. Controversies over how to share fish catches would seem more likely to happen if the zonal attachment varies randomly, or if it depends on the intensity of exploitation. As to the latter, it could, for example, be the case that a more intensive exploitation by one particular country would prevent the stock from migrating into other countries' economic zone, as seems to be the case for the Norwegian spring spawning herring (see Hannesson [2004]). The incentive to exploit such a stock cooperatively would in that case obviously be less than otherwise. Another complication could arise from age-dependent migration patterns, such as young fish being recruited from Country A's zone into Country B's zone, from where they would migrate back into Country A's zone as they grow older. These settings will not be further discussed in this paper, which is concerned with analyzing the zonal attachment principle on its most favorable terms.

Many authors have taken a game theory oriented approach to the problem of sharing fish stocks (see, for example, Hannesson [1997], Kennedy [2003], and a special issue of Marine Resource Economics edited by Bjørndal [2000]). None has, however, analyzed the zonal attachment principle. The purpose of the present paper is to fill that hole in the literature.

STOCK-INDEPENDENT UNIT COSTS

The cooperative solution

Let X denote the initial size of a fish stock and S the size of the stock at the end of the fishing period. Assume for simplicity that fishing and natural growth are two separate processes, with fishing taking place prior to growth. The initial stock in period t therefore is

$$X_t = G(S_{t-1}) + S_{t-1}$$

where $G(.)$ is the surplus growth of the fish stock.

At $t = 0$ we start with some stock X_0 inherited from the immediate past. Assume that $X_0 > S^o$, the stock that it would be optimal to leave behind, sometimes called escapement.[3] The cooperative solution to the stock management problem can then be formulated as

$$\max\text{imize } p\left(X_0 - S\right) + pG(S)/r$$

where r is the discount rate and p is the net price of the fish (market price less cost per unit of fish, assumed constant). The optimum solution is given by

[2] Bjørndal (1987) has estimated a production function for herring that implies a weak dependence of the unit cost of fish on the size of the stock. This is due to fishing on fish aggregations that are relatively easily detected. This also characterizes the blue whiting fishery.
[3] In the numerical examples below, the initial stock is set equal to the returning stock in equilibrium, i.e., $X_0 = G(S) + S$.

$$G'(S^o) - r = 0$$

The non-cooperative solution

Now let us assume that there are two players (countries) sharing the stock, both having the same net price of fish. If the cooperative solution is realized, they must have agreed on a sharing parameter α, defined as the share of the dominant player in whose zone the fish spend more than half of their life.[4] The question now is how α will compare to the zonal attachment parameter β reflecting the share of the stock in the economic zone of Player 1, the dominant player. The growth of the stock, which takes place after the fishing is over, depends on the sum of stock components left behind by both players. Player 1's maximization problem therefore is

$$\text{maximize } p\left[\beta X_0 - S_1\right] + p\left[\beta G(S_1 + S_2) + \beta\left(S_1 + S_2\right) - S_1\right]/r$$

and analogous for Player 2. The optimal escapement (S_1^o) for Player 1 is given by

$$\beta G'(S_1^o + \bar{S}_2) + \beta - 1 - r = 0$$

and for Player 2

$$(1-\beta)G'(\bar{S}_1 + S_2^o) - \beta - r = 0$$

with the bar over *S* indicating that the player takes the stock level in the other player's zone as given. These first order conditions could only be satisfied simultaneously for both players if β = 0.5. Hence we conclude that the first order condition can only be satisfied for the dominant player. For the minor player the expression will be negative, implying that he will take all of the stock that he finds in his zone. He will nevertheless be able to free ride on the dominant player and get some fish in every period, as some of the stock growth realized due to the dominant player leaving behind some of the stock in his zone will spill over into the minor player's zone.

It may, furthermore, be noted that even the dominant player could have an incentive to wipe out the stock in his own zone in a competitive solution. Provided that $G''(S) < 0$, the critical value of β is

$$\beta > \frac{1+r}{G'(0)+1}$$

This is a variant of Clark's classic result for viability of a stock under time discounting (Clark, 1973). The dominant player gets a share β of the marginal growth of the stock. Therefore, $\beta[G'(0) + 1] > 1 + r$ is necessary in order to make the stock an interesting investment object for the dominant player. Another angle on this is that extinction of a fish stock becomes much more likely the greater the number of countries or management units sharing the stock.

---

[4] By dominant player I mean the player with the largest share of the stock, according to the zonal attachment, not first mover advantage.

Incentives to achieve the cooperative solution

Now to the question what it would take to persuade the minority player to accept the cooperative solution. Would a share 1 - α = 1 - β be sufficient? The sustained profit in the cooperative solution is

$$(1-\beta)pG(S^o)$$

while in the non-cooperative solution it is

$$(1-\beta)p\left[G(S^*)+S^*\right]$$

where S^* is the stock level the dominant player leaves behind in the non-cooperative solution (the other player leaves nothing behind, as already demonstrated). From the first order condition for the dominant player and the condition for the globally optimal solution we have

$$G'(S^*)=\frac{1-\beta+r}{\beta}>r=G'(S^o)$$

which implies $S^* < S^o$ and $G(S^*) < G(S^o)$, but not necessarily $G(S^o) > G(S^*) + S^*$. Hence we cannot say anything in general about whether 1 - α = 1 - β will ensure that the minor player will prefer the cooperative solution.[5]

For a further illustration, consider a numerical example based on the well-rehearsed logistic growth equation

$$G(S)=a\left[S_1+S_2-\left(S_1^2+2S_1S_2+S_2^2\right)\right]$$

$$G'(S)=a\left(1-2S_1-S_2\right)$$

where the carrying capacity of the environment has been normalized at unity. Let a = 1 and r = 0.05. In order to make the cooperative solution attractive, the minor player has to be offered a share in the profit from the cooperative solution which gives him at least as much as what he could get from the non-cooperative solution. Figure 1 shows what his share (1 - α) has to be. For the most part it is higher than the minor player's zonal attachment coefficient (1 - β), bur for low values of β it is in fact lower. The reason for the latter is that the dominant player would deplete the stock to a very low level if he does not have much more than half of it, making the non-cooperative solution a very unattractive one. A small share of the much more profitable cooperative solution would then be attractive for the minor player. An implication of this is that the zonal attachment principle is more likely to work the more equal are the shares of the two players. In the example we see that the minor player would be happy to accept a share of the cooperative profits that are equal to or even less than his share of the stock if the dominant player's share is less than 0.6.

[5] To fully compare the non-cooperative and cooperative solutions, we would need to include also the initial adjustment of the stock, i.e., X_0 - S^o and X_0 - S^*. Since the latter is greater than the former, the non-cooperative solution becomes somewhat more attractive, but this does not change the general conclusion that sharing based on zonal attachment is not necessarily incentive-compatible.

Figure 2 shows the optimal escapement for the dominant player. With $\beta = 1$ it is identical to the sole owner solution. Furthermore we see that the critical value of β is 0.525. For the assumed value of *a* the dominant player has to have at least 52.5 percent of the stock in his zone in order to ensure its viability in the non-cooperative solution, even if the minimum growth rate of the stock passes the minimum rate of return test by a wide margin. Another way to look at this is to say that the viability of shared stocks with unit costs independent of the stock size will be assured in a competitive equilibrium only if the dominant player controls more than fifty percent of the stock, and the more so the lower is the growth rate of the stock.

STOCK-DEPENDENT UNIT COST

When the cost per unit of fish depends on the size of the exploited stock the cooperative solution is more likely to be achieved. The general reason is that both parties become more interested in fishing from a large stock in order to keep the costs down. Here we shall look at a perhaps a bit special but nevertheless very popular case where the cost per unit of fish is inversely proportional to the stock. This particular case comes from two assumptions; (i) that the cost (c) per unit of fishing effort is constant, and (ii) that the instantaneous catch is the product of effort and the stock times eventually a scaling parameter. We normalize effort (E) so that the scaling parameter is equal to one, so that the instantaneous cost per unit of fish becomes $cE/ES = c/S$. With p now denoting the market price of fish, the net revenue (rent) from reducing the stock from X to S over a fishing season will be

$$\int_S^X (p - c/s)\,ds = p(X - S) - c(\ln X - \ln S)$$

The cooperative solution now involves

$$\text{maximize } p(X_0 - S) - c(\ln X_0 - \ln S) + \left[pG(S) - c\left(\ln\left(G(S) + S\right) - \ln S\right)\right]/r$$

which yields the first order condition for maximum

$$p\left[G'(S^o) - r\right] + (r+1)c/S^o - c\left(G'(S^o) + 1\right)/\left(G(S^o) + S\right) = 0$$

The above cost function implies that the stock is evenly distributed over its area. Fishing down the stock to its break-even level implies $S = c$. With the same costs characterizing both countries, the break-even stock levels in the two countries' areas will be βc and $(1 - \beta)c$ respectively. Hence the non-cooperative solution involves

$$\text{maximize } p(\beta X - S_1) - \beta c[\ln \beta X - \ln S_1]$$
$$+\left\{p[\beta G(S_1 + S_2) + \beta(S_1 + S_2) - S_1] - \beta c\left[\ln \beta\left(G(S_1 + S_2) + \beta(S_1 + S_2)\right) - \ln S_1\right]\right\}/r$$

and analogous for the other player. From this we get, for Player 1

$$p\left[\beta G'(S_1^0+\bar{S}_2)+\beta-1-r\right]+\frac{\beta c(r+1)}{S_1^o}-\frac{\beta c\left[G'(S_1^o+\bar{S}_2)+1\right]}{G(S_1^o+\bar{S}_2)+S_1^o+\bar{S}_2}=0$$

and for Player 2

$$p\left[(1-\beta)G'(S_1^0+\bar{S}_2)-\beta-r\right]+\frac{(1-\beta)c(r+1)}{S_1^o}-\frac{(1-\beta)c\left[G'(S_1^o+\bar{S}_2)+1\right]}{G(S_1^o+\bar{S}_2)+S_1^o+\bar{S}_2}=0$$

where a bar over the other player's S means that it is taken as given. In contrast with the previous case of stock-independent unit costs, the first order conditions are now satisfied simultaneously for both players, and it not optimal for either of them to wipe out the stock in his zone.

To analyze the incentive compatibility we resort to the same example as in the previous section, with p = 1 and c = 0.2, which implies a break-even stock level at 20 percent of the pristine state biomass. Figure 3 summarizes the results. Also here it could be necessary to give the minor player a larger share in the cooperative profits than corresponds to his zonal attachment parameter. The difference between the zonal attachment parameter (1 - β) and the required share in the cooperative profits (1 - α) is less here, however, than with stock-independent unit cost (cf. Figure 1). As in the previous case, the zonal attachment principle is more likely to work the more equal are the shares of the dominant and the minor player.

CONCLUSION

This paper has shown that fish stock sharing agreements based on zonal attachment need not be incentive compatible. It may be necessary to give a minor player a larger share in the cooperative profits, or of the total permitted catch, than corresponds to his share of the stock, in order to make him better off than he would be in the absence of cooperation. This is all the more likely to happen the smaller is the minor player's share of the stock. The minor player will be able to free ride on the conservation efforts of the dominant player, and the conservation incentives for the dominant player will be stronger the larger is his share of the stock. Stock-dependent unit costs of fish make it less likely that the minor player will need to be enticed with a larger share in the cooperative profits than his share of the stock, or will at any rate diminish the necessary "overcompensation."

These results could explain why it has been difficult to reach agreement on some stocks in the Northeast Atlantic where the zonal attachment principle apparently is strong. It is perhaps surprising, given these findings, that the stock sharing agreements for the North Sea stocks have been unchallenged for twenty years or more. For these stocks the unit costs of fish are, however, probably more sensitive to the stock size than for the stocks for which no agreements have been reached. This could explain why the agreements on the North Sea stocks have been so resilient.

REFERENCES

Bjørndal, T. (1987): Production Economics and Optimal Stock Size in a North Atlantic Fishery. Scandinavian Journal of Economics, 89:145-164.

Bjørndal, T. (2000): Special Issue Introduction. *Marine Resource Economics* 17:261-263.

Clark, C.W. (1973): Profit Maximization and the Extinction of Animal Species. *Journal of Political Economy* 81:950-961.

Engesæter, S. (1993): Scientific Input to International Fish Agreements. *International Challenges*. The Fridtjof Nansen Institute Journal, Vol. 13, No. 2, pp. 85-106.

Hamre, J. (1993): A Model of Estimating Biological Attachment of Fish Stocks to Exclusive Economic Zones. *International Council for the Exploration of the Sea*, C.M. 1993/D:43, Copenhagen.

Hannesson, R. (1997): Fishing as a Supergame. *Journal of Environmental Economics and Management* 32:309-322.

Hannesson, R. (2004): *Sharing the Herring: Fish Migrations, Strategic Advantage, and Climate Change*. Unpublished paper, Centre for Fisheries Economics, Bergen.

ICES (1978): The Biology, Distribution and State of Exploitation of Shared Stocks in the North Sea Area. *Cooperative Research Report* No. 74, International Council for the Exploration of the Sea, Copenhagen.

Kennedy, J. (2003): Scope for Efficient Multinational Exploitation of North-East Atlantic Mackerel. *Marine Resource Economics* 18:55-80.

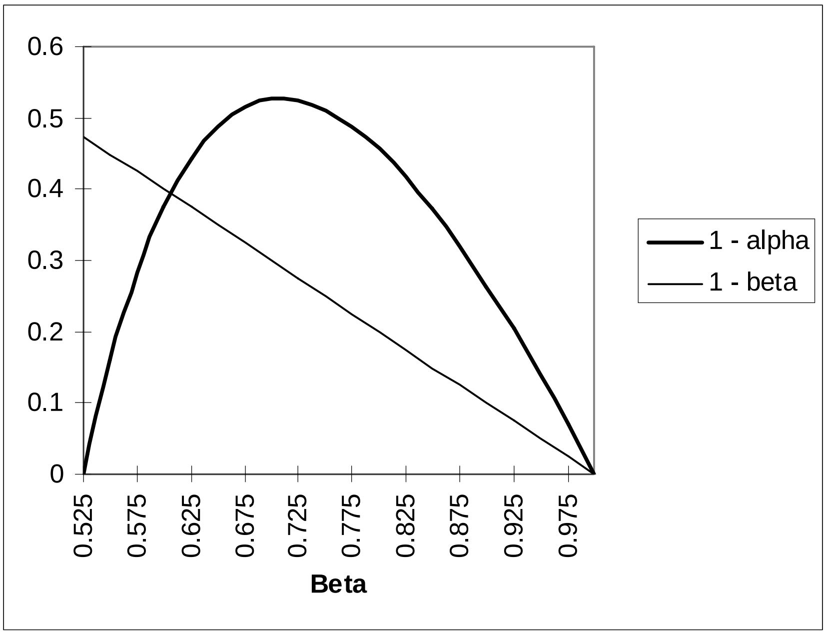

Figure 1

Minimum profit share (1 - α) of the minor player in the cooperative solution compared to his share (1 - β) of the stock. Stock-independent unit cost of fish.

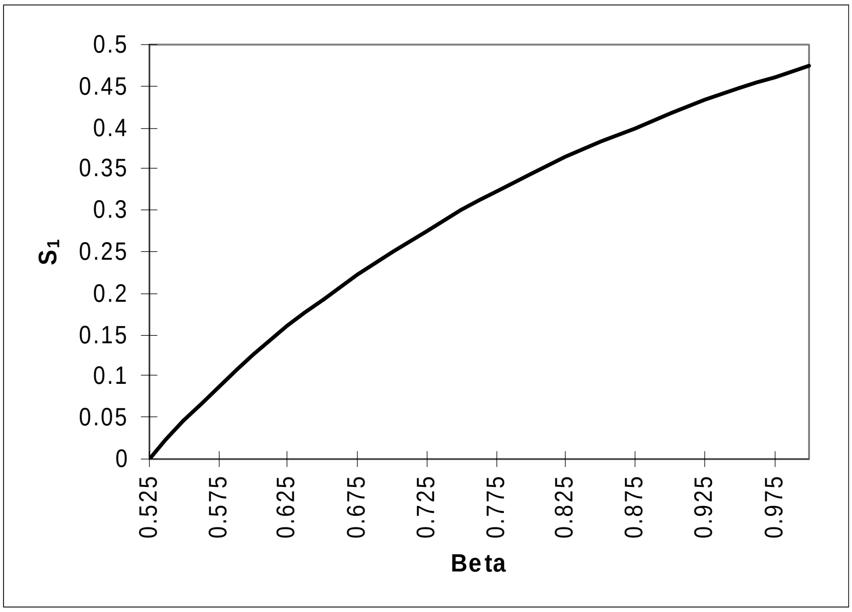

Figure 2

How the stock (S_1) optimal for the dominant player changes with his share (β) of the stock. Stock-independent unit costs.

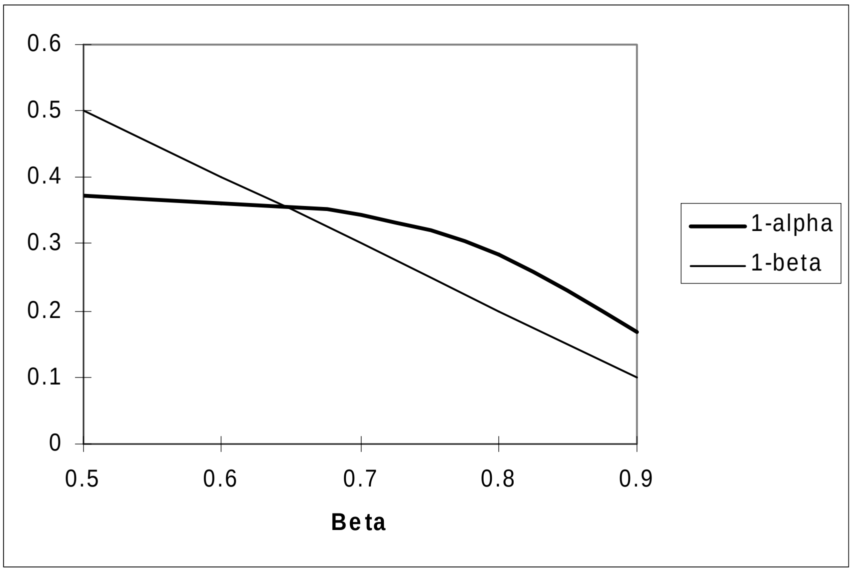

Figure 3

Minimum profit share (1 - α) of the minor player in the cooperative solution compared to his share (1 - β) of the stock, with stock-dependent unit cost of fish.