Robustness of Sharing Rules under Climate Change
The Case of International Fisheries Agreements

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Abstract

Many international fisheries agreements involve sharing rules. The current paper analysis the stability of sharing rules when coping with long run changes in the composition of fish stocks in an international setting due to climate change. The exploitation of the cod stock in the Baltic Sea serves as an illustrative example. These rules are normally stable rules, but this is only true if they are not contingent on shifts in the relative distribution of density of the resource. Given the projected climatic changes in the latest IPCC report the stability of these agreements is not guaranteed. The lack of robustness of management systems of shared fish stocks with respect to exogenous changes has been addressed in several papers (see e.g. Miller (2005) and Miller and Munro (2004)). This paper builds, however, on a more rigorous game theoretic analysis conducted by Kronbak and Lindroos (2005). The main findings of this paper is that, when externalities are present, a decrease in the resource rent implies that the threat for not free riding become less serious and thereby leave less room for stable solution. Generally speaking, this implies that climatic changes with a negative effect on the resource rent make joint solutions less likely.

Keywords: Climate Change, Cooperative Games, Stability of Fisheries Agreements.

JEL classification: C62, C70, Q22, Q54.

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1. Introduction

The latest report from IPCC (IPCC 2001) assesses that average global temperature will rise by approx. 1.2-5.8 degrees over the next 100 years. Many international environmental treaties and international resource sharing arrangements will be affected by these climate changes. International fish sharing arrangements, in particular, are vulnerable to climatic changes, since such changes directly affect the spatial distribution, growth, migration and recruitment of the fish resource, variables that affect the stability of such agreements.

This paper addresses this issue, by setting up an age-structured model with a Beverton-Holt recruitment function for the Baltic Sea cod fishery. The fishery is assumed to be exploited by three groups of countries. These players can form different coalitions, allowing for a total set of 8 different coalition formations. The coalitions, also including the singletons, are assumed to choose strategies that maximize their economic benefits over a time horizon of 50 years. The coalitions are interpreted as agreements over shares of quotas. Moreover, an externality exits in the exploitation of the resource, since too high catches (too many quotas) today imply less catch opportunities in the future. Such agreements are, however, vulnerable to free riding e.g. catching more then the agreed quotas. In essence, our paper analyses whether climate change increase or decrease the incentives to free ride. These incentives are interpreted as a measure for the change in robustness, or more precisely, the model explores how the stability of a grand coalition changes if an exogenous affect such as a climate change alters the biological settings of the fishery. This paper contributes by exploring the relation between the joint benefits and the free rider benefits when externalities are present. In addition, the paper elaborates on how this relation changes when the ecosystem faces exogenous shifts such as global changes.

By implementing our model, we show that if a climate change adds value to the resource stock by increasing the size of the biomass or a larger fraction of mature fish, then other things being equal, there is a larger room for stable joint solutions. If the contrary is true, for instance a reduction in the recruits per spawner, then there is less room for stability. Even though we focus on the particular case of the Baltic Sea, this case carries with it sufficient generality to draw more general lessons. It shows how climate change might affect the stability property of resource sharing arrangements, but since the applied model is fairly general, its results are also applicable to many other international resource sharing arrangements. Our basic focus is on how the room for free rider stable solution changes when climate changes occur.

Many fish resources are no longer subject to open access but rather exploited by a limited group of countries in an agreement setting. The UN law of the sea commission makes the distinction between two types of managerial challenges concerning "transjuridictional" fish resources: management of shared stocks (fish that migrate between the EEZs of two or more states)[1] and conservation of straddling fish stocks (fish that migrate between EEZs and the waters beyond).[2] Climate change poses a challenge to both types of fish resources.

Several papers analyze on a case basis the effect of the emerging climate changes on the stability of agreements. Miller (2005) mostly (exclusively) analyses cases of highly migratory fish resources (such as the Pacific northeast salmon, and tropical tunas. The main effect of (temporary) climate changes is that the fish resource moves so that the premises the agreements rest on change, making the agreement unstable.[3] Miller (2005) and Miller and Munro (2004) conclude on the basis of a study of several commercially important shared fish

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1 Some of the more important ones are: the EU-Norway fishing agreement of 1980 on shared stocks, Denmark, Iceland, Norway concerning capelin stock between Greenland, Iceland and Norway, Norway-Russia in Barents sea (with 3 party access), Australian-Papa New Guinea (shared stock in Torres Strait), the Baltic Sea Fisheries commission concerning shared stocks in the Baltic Sea, the Pacific Salmon agreement between the US and Canada.

2 The most well-known example in Europe is probably the Nothern Atlantic Bluefin Tuna.

3 The conclusions are also present in the following quote from abstract in Miller (2005), where she discusses the provision by the 1995 United Nations Fish Stock Agreement of a legal framework for the creation of regional fishery management organizations (RFMOs): "The stability and success of those organizations will depend, in part, on how effective they can maintain member nations' incentives to cooperate, despite the uncertainties and shifting opportunities that may result from large climate-driven changes in the productivity or migratory behavior of the fish stocks governed by the agreement".

stocks that the main management challenge in the presence of climatic changes (in the analyzed cases) is that limited understanding and poor predictability of the biological impacts contribute to the dysfunction or even breakdown of existing cooperative arrangements.[4] The lessons from this can be used to predict climate change related instability of institutionally similar treaties, like the treaty between Norway and Russia: Shared fish stock in the Barents Sea between Norway and Russia (cod, haddock, and capelin). Since this treaty is based on a fixed initial allocation key (Stokke 2003) in the Baltic Sea until 2006, the allocation of TACs has, for individual species (cod, herring, sprat, salmon), also been based on fixed percentages (Ranke 2003). The above results would, therefore, again predict instability of the treaty. However, since we do not consider movements in the stock, which we do not consider likely in the Baltic Sea for the expected changes in temperature, our conclusion shows, for most of the parameter values, a more stable situation.

One of the main findings is that climatic changes increase the scientific uncertainty which most agreements rely on. This highlights the need for better information or the need for a flexible management system that can cope with shifting environments. In contrast to these papers, our paper provides a more rigorous game-theoretical approach, which we believe is necessary to reduce the uncertainty stemming from expected climate change. We adapt the case of Baltic cod fisheries. We, however, find that this particular case carries lessons for many shared fisheries, where a trend in climate slowly changes the environmental conditions for the fish stocks.

The paper is organized as follows: Section 2 describes the condition for stable agreements when externalities are present. In section 3, the effect of climate changes on fisheries is discussed, while section 4 introduces the model. The results of the simulation of the various scenarios are presented in section 5, while section 6 concludes the paper.

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4 A better understanding of the role of unanticipated climatic trends of shifts in current resource - management disputes may help to smooth the path of adaptation, for example, by encouraging the development of more flexible allocation rules (Miller and Munro, 2004).

2. Stability of Agreements and Externalities

The classical approach to cooperative games is based on the fundamental assumption that the players have already agreed to cooperate and that the model allows for transferable utility. The coalition game is a subgroup of the cooperative game, since it allows for a group smaller than all the players (a coalition) to cooperate. For both cooperative and coalition games the stability has to be evaluated after the solution to the game is determined. The crucial point for stability is the way the benefits inside the cooperation are shared among the players (the sharing rule). The classical theory of games in coalitional form is not fully satisfactory, since it ignores the possibility of externalities. This typically means that the action available to a coalition is assumed to be independent of the actions chosen by non-members (Greenberg 1994). Since this paper deals with the extraction of a renewable resource by several agents, externalities are present, and the classical approach is inappropriate. The paper therefore applies the partition function approach where the worth assigned to every coalition depends on the entire coalition structure. The essence of this approach is that the presence of externalities affects the success for stable coalition structure. The partition function approach is applied to the management of high sea fisheries stocks (Pintassilgo 2003) and as a stability measure approach in Kronbak and Lindroos (2005), which includes the free rider values as threat points. This paper contributes to the literature by exploring the important connection between the stability of management agreements in fisheries when the resource stock is subject to exogenous changes such as a climate change.

2.1. Requirements for a Stable Agreement

On a very general level, for an agreement in international society to be stable, Barrett (2003) argues that an agreement must contain the following five elements. It should create an aggregate gain, contain a rule for distribution of the aggregate gain in a fair manner, it must be able to deter both non-compliance and non-participation and deter entry: non-participants should not exploit the agreement. Some of these five elements are addressed in our analysis. We do not explicitly consider these points, but with regard to internal stability, we say that the stability of an agreement is increased when the aggregate gain increases relatively the free riding gains. In such cases, free riding is less attractive, and there will be a "larger" set of sharing imputations that could form a stable agreement. It can also be easier to deter free riding and non-compliance, since more surpluses are available. Both free riding and noncompliance contain a risk of compromising the agreement. Therefore, the higher the gain in the grand coalition, the less likely free riding and non-compliance become.[5]

3. Climate Change and its Effect on Fish

Climate change most likely results in a long run increasing trend in the average air temperature, but with large amounts of uncertainty, in particular regionally.[6] The latest IPCC report (IPCC, 2001) predicts a 1.2-5.8 degree increase over the next 100 years. Most generally, in specific geographical areas, climate changes might both have negative as well as positive effects on the growth rate or the availability of renewable resources, like fish stocks or forests. The climatic variation is likely to have an impact on fish stock parameters, such as spatial distribution, growth, migration and recruitment.

The main focus in this paper is on size and recruitment, since these are the most relevant factors for Baltic Sea cod (See Köster *et al.*, 2005). An expected temperature increase affects recruitment and size, both directly, but also through the effect on salinity and oxygen content in the water, which in turn affects the fish

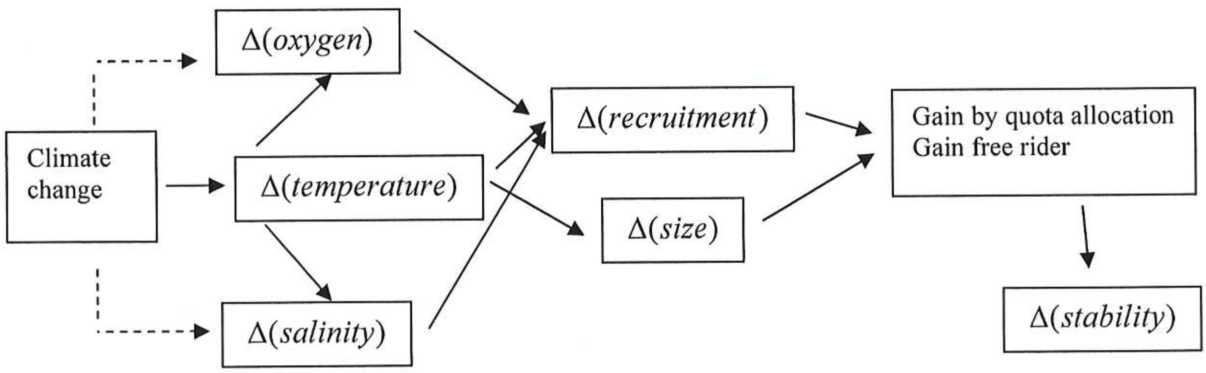
5 We measure the excess gain of the agrement relative to free riding in the with/without climate change. The simple says that for unchanged probability that the agreement breaks down upon free riding of non-compliance, the larger the total gain, the less likely free riding or non-compliance will be.

6 Also changes in the presence and strength of wind (-fields) are expected in response to climate changes, which again affects fish stocks. For cod: The biomass of zooplankton, the main food for larval and juvenile fish, is generally greater when temperature increases by up to 5 degrees (in the Barents Sea). High food availability for the young fish results in higher growth rates and greater survival through the vulnerable stages that determine the strength of a year-class. Temperature also affects the development rate of the fish larvae directly, and consequently, the duration of the high-mortality and vulnearble stages decreases with higher temperature.

resource. It is most likely that an increase in temperature reduces the level of oxygen, and to some extent, the salinity in the Baltic Sea.[7] The oxygen content is directly affected by changes in wind, changes in inflow of waters from North Sea and changes in temperature.[8] The salinity is mostly affected by changes in precipitation and changes in fresh-water runoff and inflow from the North Sea. Here again, the general prediction is that salinity is likely to fall. The schematic overview of effects is shown in figure 1, where the notation in the last two boxes refers to the coalition and free rider profits and stability of the grand coalition, and will be explained in a sequel.

There are some estimates of the potential sizes of the effect of climate change to recruitment and growth of the resource. The overall result is that changes in average bottom temperature affect two factors: both recruitment and the growth rate of the fish.

Figure 1. Schematic picture over how climate change affects stability in the Baltic Sea[9]



7 In a multispecies context, an increase in water temperature favours the reproductive capacity of sprat, i.e., sprat reproductive success increases, which may be unfavorable for the cod due to the potential increase in predation pressure by adult sprat in the early life stages of cod (quotation from Röckmann *et al* 2006, page 4).

8 This is due to increased oxygen-consuming demineralisation of organic materials, but also because increasing water temperature reduces oxygen resolution (Röckmann *et al.* 2006).

9 A more thorough picture can be found in Roessig *et al.* (2005).

3.1. *Relation between Size and Temperature*

In general, higher temperature increases the size of a mature fish. We assume the fish response to climatic changes as:

$$S_t = \left(\prod_{i=1}^{t} \left(1 + \alpha_i (T)_i\right) \right) \cdot S_0 + v_t^S \tag{1}$$

The size of a representative fish with age *t* is the product of the annual increases $(\alpha_i(T))$ and S_0 is the initial size, the size of a hatched individual. T_i is the annual mean bottom temperature and $v_t^S = \sum_{i=0}^{t} v_i$ is a sum of random variables with mean zero and constant variance.

In this general notation, the annual increases are allowed to differ, but in our simulations we make the simplifying assumption that these are equal and without any error, such that the size-function is written as:

$$S_t = \left(1 + \alpha(T)\right)^t \cdot S_0 \tag{2}$$

It is generally asserted that $S_T^{'} > 0$ for all relevant T_t (Mazzi 2005).

Finally, in the simulation we use weight (*W*) rather than size, and length (size) and weight are interconverted using a estimated length-to-weight ratio: $W = 0.0104 S^3$ (Clark *et al.* 2003).

3.2. *Relation between Recruitment and Temperature*

The recruitment-temperature relationship is more complex. Recruitment tends to increase with rising temperatures for cod living in colder waters at the northern extent of their range (bottom temperatures less than 5°C). At the southern limits of their range, recruitment tends to decrease in warmer waters (above 8.5°C). Temperature tends to have no effect on recruitment for cod living in the mid-range of bottom temperatures. Present cod stocks are not observed to occupy waters with annual mean bottom temperatures greater than 12°C. This may be due to too high metabolic costs, lack of ability to successfully compete with warmer-water species, or reduced survival of their eggs and larvae. Regardless of the reason, if future bottom temperatures warm up to beyond 12°C in the future, the assumption is that the cod will disappear.[10]

We assume that recruitment is given by $R_t = R_t(T_t) + \varepsilon_t$, where the recruitment at time t R_t, is a function of the annual mean bottom temperature T_t, and ε_t is a random variable both with mean zero and constant variance. There are several mechanisms through which temperature changes affect the number of recruits by affecting the number of surviving juveniles, and the age at which recruits become sexually mature. All in all, temperature will affect yield per recruit, i.e., the mean long term yield in weight from each individual fish that is recruited to the exploited stock.

In spite of large uncertainties, some general lessons regarding the effect from temperature on the recruitment function can be drawn:[11]

For $T \in [0;5]$, $E[R_t(T_t)]$ is mainly greater than zero
For $T \in [5,8;5]$, $E[R_t(T_t)]$ is close to zero (3)
For $T \in [8.5;12]$ $E[R_t(T_t)]$ is mainly less than zero
For $T_t \neq (0,12)$, $R_t(T_t) = 0$,

where $E[R_t(T_t)]$ refers to the expectation about changes in recruitment when temperature changes.

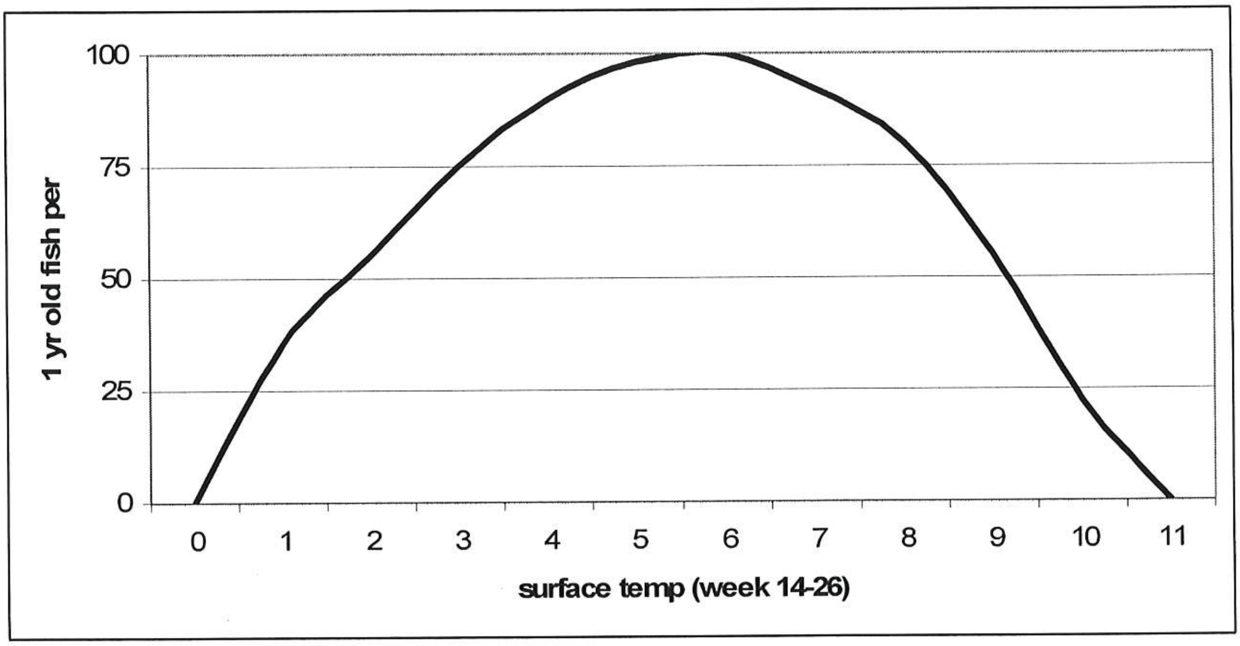
10 It does, however, also show uncertainty. Moreover, regional factors might influence the correlation, such that it not necessarily can be used in other regions. Dalpadado and Loeng (----) present data from the Barents Sea showing a highly positively correlation between 0-group cod length and annual mean (water) temperature.

11 Conclusions from Brander (2000, 2005).

In figures 2a and 2b an observation between temperature and the size of juvenile cod is depicted from the Barents Sea. It is seen that growth reacts significantly to already small changes in temperature.

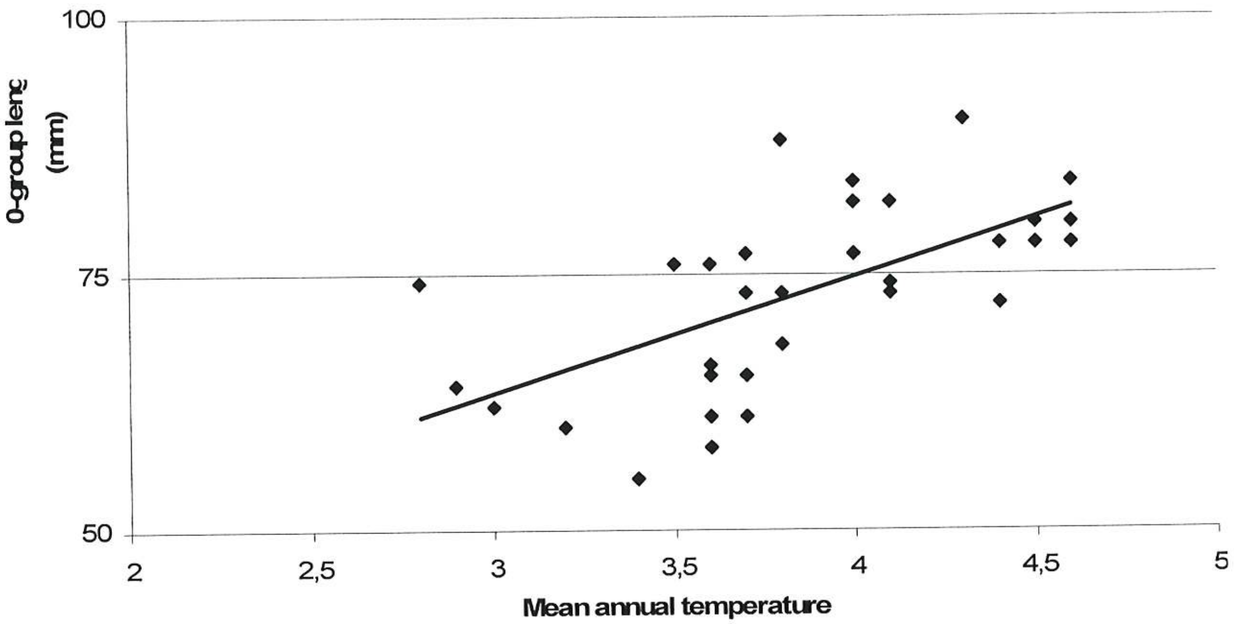
Given these observations, the following more general model can be made. Generally, the size of the stock at any time t, X_t (measured in biomass), is a function of past and present recruitment (R), past and present size, fishing pressure (F), and past and present natural mortality (M): $X_t = X_t(R_t, R_{t-1}, R_{t-2},,,,, S_t, S_{t-1}, S_{t-2},,,, F_t, F_{t-1}, F_{t-2},,,, M_t, M_{t-1}, M_{t-2},,,)$. We will not include possible links between natural mortality and changes in temperature.

Figure 2a. Relation between number of 1 year old cod and the temperature



Source: Brander (2005).

Figure 2b. Variation in 0-group cod length and annual mean temperature during 1965-1997, Barent Sea[12]



Source: Ottersen and Loeng (2000).

4. The Model

From an economic point of view, it is not the amount of fish, but the amount of fish per weight that is relevant, given that larger fish has the same market value as smaller fish. The value, V_t, (or rather the biomass) is the number of fish times the size. We assume that the price of fish is constant, which is a common assumption in the literature. Furthermore, denote by $\pi_t = \pi_t(V_t)$, the profit function for the relevant agents. Throughout, we assume that $\frac{\partial \pi_t}{\partial V_t} > 0$. From this we derive the relevant scenarios that will serve the route for the analysis to come.

12 The observation are from the Barent sea, the Kola Section. The functional form of the linear relationship is $S(T) = 11.364T + 29.188$, $R^2 = 0.3782$. We note that there are several outlayers, but the positive relationship between temperture and size is evident.

The basic scenario is the simulation without a climate component. It corresponds to the one reported in Kronbak and Lindroos (2005).
The second scenario is the case, where climate change only affects recruitment (i.e., keeping fish size constant). The part defined by $\frac{\Delta V_t}{\Delta T_t}|_{\Delta S_t=0}$.

As long as recruitment increases biomass, the consequence will be that costs pr. fish caught will be reduced. Moreover, re-optimization is likely to occur, and the total effect is an increase in π since the country will always be able to keep catches unaffected, in which case profits increase.

The third scenario is the case, where climate change only affects size (i.e., keeping recruitment unchanged). The part defined by $\frac{\Delta V_t}{\Delta S_t}|_{\Delta T_t=0}$.

As long as the size is increased, the same amount of fish implies higher catch weight, (a larger biomass); such that for constant number of fish caught, revenue increases and costs fall. (Again, the level of catch might change due to re-optimization). The implication is, again, higher profit.

The fourth scenario combines the effect of scenarios 2 and 3 and implies a change in biomass from two sources, namely an increase in weight and a decrease in recruits per spawner.

Assume that an increase in the value of the stock occurs. This can basically happen from two channels through which the temperature affects the stock, through changes in the recruitment and through the size of the fish. What is important for the stand-alone stability property is how large the gain from profit is compared to size of the free riding gains. This gives a measure of how large the area, where cooperation is feasible, is. Let $\pi^{\sum i}$ denote the total profit from full cooperation or the grand coalition, while π_i^{FR} denotes the free riding profit to country *i*, when coalition $S \setminus \{i\}$ still cooperates. The following measure denotes whether the room for stand-alone stable solutions increases (positive measure) or decreases (negative measure) when compared to different scenarios. It measures the absolute change in the excess of economic benefits for a stand-alone stable coalition when comparing the basic scenario with scenarios after climate changes:

$$\frac{\Delta[\pi^{\sum_i} - \sum_i \pi_i^{FR}]}{\Delta T} \tag{4}$$

where T describes the change in temperature. Thus, the above formula describes the additional benefits or costs when climate changes have occurred that can be applied for a cooperative solution. The measure does not tell us whether the co-operative solution is stable or not. To ensure stand-alone stability the following equation has to be positive (Pintassilgo 2003).[13]

$$\pi^{\sum_i} - \sum_i \pi_i^{FR} \tag{5}$$

Not surprisingly, we find that both $\pi^{\sum_i}$ and π_i^{FR} increase as the value of the stock increases.

The Baltic Sea is a sea shared among the members of the European Union (EU) (Denmark, Finland, Germany, Sweden, Estonia, Latvia, Lithuania and Poland) and the Russian Federation. The Baltic Sea consists of the central Baltic Sea, the Gulf of Bothnia, the Gulf of Finland, the Sound and the Danish Straits. It is a fairly remote area and it contains no international waters. This model groups the countries into three players for simplicity.

The most valuable fishery in the Baltic Sea is the cod fishery which, until 2006, was managed by the International Baltic Sea Fishery Commission (IBSFC).[14] All the parties exploiting the cod stock are members of the IBSFC, which sets an agreement for the total allowable catches (TACs) for the fishery. Seemingly,

13 For the sake of tractability, in our paper we only deal with three players, which explains why we consider benefits from singleton free riders and not from smaller coalitions free riding.

14 The IBSFC as an organisation ceased to function from January 2006.

there is a coalition, since TAC measures are jointly agreed upon by all IBSFC parties but, basically, the TACs are allocated according to fixed distribution keys (Ranke 2003).

The model applied is a standard type of cohort-model, applying a Beverton-Holt stock-recruitment relationship. The motivation for this is that climate changes can have different effects on the different cohorts. The catch function is therefore also defined by the fishing mortality imposed by each country on each cohort. This type of catch function also allows for selectivity in the different cohorts. The cost function depends on the total yield relative to the total biomass. For a thorough description of the model please see Kronbak and Lindroos (2005). The benefits from different coalitions and for free riders are calculated.[15] The aim of this approach is to define the area that allows for internal stability. Any agreement that results in an outcome that lies in this area will be stable against free riders. Comparing the free rider profits and the grand coalition profit allows us to check for stand-alone stability.

5. Scenario analysis

So far, we have been rather vague about how exactly temperature changes recruitment. In order to make a simulation, we need to operationalize the recruitment function. The following section goes, therefore, into detail in the different scenarios applied in the model.

5.1. Basic scenario

The basic scenario applies the parameter values given in Kronbak & Lindroos (2005).[16] In particular, initial values for stock weight are given by the ICES (2000) 1998-estimates. The stock recruitment function follows an age-

15 We define free riders as a player leaving the grand coalition to form a singleton coalition, holding the rest of the colition structure constant.

16 Only changes to this model will be highligthed here.

structured Beverton-Holt stock-recruitment relationship, identical to the one used by ICES (2000), defined as follows:

$$R_t = \frac{cSSB_{t-1}}{1 + bSSB_{t-1}} \tag{6}$$

where c and b are biological recruitment parameters; c is the maximum recruits per spawner at low spawning stock size and c/b is the maximum number of recruits when the spawning stock biomass is very large.[17] SSB_t is the spawning stock biomass in year t. The biological parameters of the stock recruitment relationship are summarized in table 1.

Table 1. Stock-Recruitment (B-H) Parameter Values

Parameter	Value
c	0.9814216
b	0.000002340

Source: ICES (2000).

We apply the weight-temperature relationship reported in Clark *et al.* (2003):

$$G = (\gamma_1 + \delta_1 \cdot T) \cdot W^{(\gamma_2 + \delta_2 \cdot T)} \tag{7}$$

where G is the growth rate (% day $^{-1}$), W is the weight of the fish (g) and T is the experimental temperature. The parameters in Clark *et al.* give the following expression:[18]

17 The stock-recruitment estimated by ICES assumes that recruits do not enter the population before age 2. Therefore, the SSB lags two years in the Beverton-Holt recruitment function applied by ICES (2000). For simplicity, we apply only a one-year lag in our simulation model. We do not see this as a critical assumption since the SSB biomass is reasonably monotone every two successive years.

18 As Clark *et al.* (2003) points to, the above expression is only valid for $W< 5000$. The expression is a estimate.

$$G = (0.42 \cdot T) \cdot W^{(-0.19-0.02 \cdot T)} \tag{8}$$

Clark *et al.* assume that the asymptotic weight of the fish is equal, that is, all fish converge to a specific weight (= 16 kg), as their age increase. Other papers, however, use a time dependent asymptotic weight, e.g., Swain *et al.* (2003). Given this, we apply the relationship $G = (0.42 \cdot T) \cdot W^{(-0.19-0.02 \cdot T)}$ in the range of $W<$ 5000 to calculate the average annual growth rates for each year of a specific individual. Since the baseline weights ($W_t^{T_0}$) are known, we only need the following expression:

$$W_t^{T_N} = \prod_{i=0}^{t} \left(1 + \alpha^{T_N/T_0}\right) W_t^{T_0} \tag{9}$$

where $W_t^{T_N}$ is the weight of the fish at age t given temperature is T_N, α^{T_N} is the average annual growth rate of the fish given temperature is T_N, α^{T_N/T_0} is the additional growth at T_N compared to base line growth at T_0 and $W_0^{T_0}$ is the weight in the base line at time 0.

The calculations are done as follows. First we calculate $G(W,T)$ for $W = \{500, 1000, ..., 5000\}$ and $T = \{4,5,6,7,8,9\}$. From this we calculate the temperature-weight growth rates for each for all temperatures and weights, e.g., $\alpha^{T_5/T_4}(500) = \frac{W(500,5) - W(500,4)}{W(500,4)}$, which is the (additional) growth rate for a 500g fish, when the temperature increases from 4 to 5 degrees. Finally, we calculate the average (additional) growth rates for each temperature, e.g., $\alpha^{T_7/T_4} = \frac{\sum_{W=500}^{5000} \alpha^{T_7/T_4}(W)}{10}$, giving the annual increase in growth rates, when the temperature increases from 4 to 7 degrees. Table 2 summarizes the results from the calculations.

Table 2. Estimates of percentage change in average growth when temperature changes

Temperature (T_N)	**4**	**5**	**6**	7	**8**	**9**
Average growth (α^{T_N})		0.07	0.10	0.10	0.08	0.04

From table 2 we can conclude that within the relevant range of temperature, there is an average growth in the stock size. What should be noted, however, is that it is not a linear growth; the maximum percentage growth is found for 6-7°C. There are, however, several problems (shortcomings) in this approach. The growth rate is measured in gram/day, and we simply transform this into percentage growth per year. However, since we use percentage changes compared to the baseline, we do not see this as a problem, except that this approach underestimates the growth, since the growth is continuous every day. To compensate for this underestimation and for sensitivity reasons we have also estimated results for growth larger than what is calculated in table 2.

5.2. *Second Scenario*

These scenarios estimate the consequences of a reduction in the maximum recruits per spawner, c, in the Beverton-Holt stock recruitment function. Initially, the parameter c is close to 1 and the consequences of a reduction in c to 0.7, 0.5 and 0.3 are estimated, since climatic changes might result is smaller recruitment.

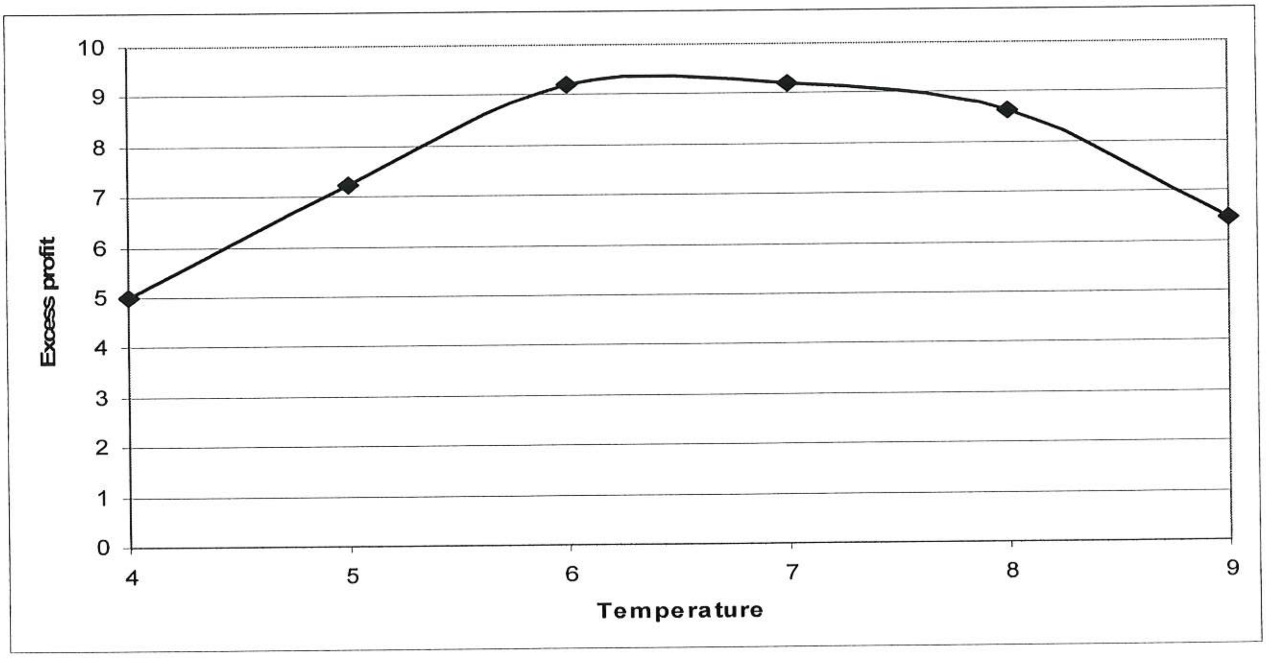
5.3. *Third Scenario*

The scenarios with increment in size deal with three different levels of increase, namely a 5, 10 and 20 % increase in stock size and in catch weight. The increment is assumed to be compounded into the cohorts such that the increment in the weight is largest for the highest year classes. The equations for the new stock weight (*SW*) and the new catch weight (*CW*) are given as follows:

$$SW_{T_N}^{a} = SW^{a}\left(1+\alpha^{T_N}\right)^{(a-1)}$$
$$CW_{T_N}^{a} = CW^{a}\left(1+\alpha^{T_N}\right)^{(a-1)} \qquad (10)$$

where $SW_{T_N}^{a}$, is the stock weight for cohort a after the increase, $CW_{T_N}^{a}$ is the catch weight for cohort a after the increase, α^{T_N}={4%, 7%, 8%, 10%, 20%} is the percentage increase in the stock size, a=2,3,…,8 are the cohorts and SW^a, CW^a are the original stock weight and catch weight respectively for cohort a. Applying the estimates for weight changes and the formula for excess profit, equation (4), we can determine how room for stable solution changes with changes in temperatures, given that temperature changes only affect the size of the fish. Figure 3 illustrates this relationship.

Figure 3. Estimates of the excess profits from a grand coalition compared to the free rider profits, when a temperature change affects only the stock and the catch weight



5.4. Fourth Scenario

This scenario combines the effects of the second and the third scenario. It illustrates the uncertainty with which climatic changes affect fish stocks. Scenarios exploited here combine worst-best scenarios from the above two scenarios. The results in the following two scenarios: First a slight increase in stock size and a great reduction in recruits per spawner and, second, a great increase in the stock size and a small reduction in the recruits per spawner.

5.5 Estimated Results

The uncertainty of what happens with climate changes is captured by simulating the four possible scenarios. We estimate the excess profit compared to free rider value to determine how the room for standalone solutions changes in the different scenarios. The estimations from the different scenarios are summarized in table 3.

Table 3. Results from estimations for different scenarios

		Excess profit from full cooperation compared to free riding.	*Change* in excess profit compared to the basic scenario (no climate change).
		In 10^9 Dkr.	In 10^9 Dkr.
Basic Scenario		5.00	-
Second scenario	Decrease in recruitment (c=0.7)	3.50	-1.51
	Decrease in recruitment (c=0.5)	2.73	-2.28
	Decrease in recruitment (c=0.3)	1.89	-3.12

Third scenario	4 % increase in size	6.46	1.46
	7 % increase in size	7.72	2.72
	8 % increase in size	8.64	3.64
	10 % increase in size	9.20	4.19
	20 % increase in size	14.19	9.21
Fourth Scenario	Increase in size (5%) Decrease in recruitment (c=0.3)	2.48	-2.52
	Increase in size (20%) Decrease in recruitment (c=0.7)	10.81	5.81

Note: Numbers are subject to rounding.

The simulations indicate that the stability area indeed increases as the value of the stock increases because the consequences of free riding (the negative externality) become more serious. From the literature (Eyckmans and Finus 2004) it is known that negative externalities provide an incentive for players to cooperate, leading to large stable coalitions. Our model investigates the effects of an increment in the value of the biomass caused by climatic changes.

The lessons to be learned from the estimations of the different scenarios are that in all the estimated scenarios there is room for a stand alone stable grand coalition. The reason for this is that the positive externality is strong enough to deter free riding from a joint solution. Furthermore, it can be seen that the room for stable sharing imputations increases if the value of the stock increases, here illustrated by increase in stock and catch weight or increase in the fraction mature. The contrary occurs if the value of the stock is decreased, as illustrated by the scenarios where the recruits per spawner are reduced. The particular size of the numbers in table 3 is not essential for the conclusions.

The results from the fourth scenario highlight the uncertainty of climate change since it gives two countervailing results. If the size of the stock grows only slightly but the reduction in the recruits per spawner is more comprehensive, then there are fewer possible sharing imputations for a joint solution. If the contrary happens, namely a relatively large effect on the stock size and only a slight reduction in the recruitments per spawner, then there is more room for a stable grand coalition compared to the scenario with no climate change.

The scenarios included in the paper give in themselves a picture of robustness and sensitivity of the model since estimates are given for different parameter values in each scenario. Therefore, the paper does not make additionally sensitivity tests. Instead the robustness is testes, e.g. what happens if other parameter values are changed, we have focused on the robustness if biological parameters are change; e.g. the fraction mature of each cohort is increased and/or the maximum recruit per spawner for high biomass level is increased. The results from this analysis are in general the same. If the change adds value to the biomass then there is more room for a joint solution compared to a situation with no climate change, while if the change decreases the value of the biomass, there is less room for a stand-alone stable solution.

6. Discussion and Implications

The paper discusses the uncertainties about what happens to the biological parameter for a species when a climatic change occurs. It formalizes the uncertainty into three different scenarios, namely a decrease in the maximum number of recruits per spawner, an increase in the stock and catch sizes and finally a combination of these two. The first two scenarios mentioned have a countervailing effect on the biomass. Within these scenarios the likelihood for stable joint solutions, compared to the basic scenario without climate changes, is estimated. The model is implemented for the Baltic Sea cod fisheries, but we find it appropriate to draw some general lessons from it. One of the main findings is that climatic changes increase the scientific uncertainty which most agreements rely on. This highlights the need for better information or the need for a flexible management system that can cope with shifting environments. Our paper provides a game-theoretical approach, which we believe is necessary to reduce the uncertainty stemming from expected climate change. We find that our particular case carries lessons for many shared fisheries, where a trend in climate slowly changes the environmental conditions for the fish stocks.

Several papers conclude, based on case studies, that climatic changes and climatic variability imply a thread of destabilizing international fisheries agreements, typically due to movements in the fish stock. Our study takes a different stand, since it concentrates on the change in abundance and size of the fish stock as a response to climatic changes. A main finding is that when the value of the stock increases, there will be more room for making a stable agreement. That is, if climatic changes increase the resource rent, then there is more room for stand-alone stable agreements. Contrary if the value of the biomass is decreased there is less room for stable agreements. These conclusions are subject to the uncertainty about actual climatic changes and the following consequences for recruitments and changes in stock size. The uncertainty becomes particularly clear in our last scenario, which shows countervailing results in the room for stability. In general, when externalities are present, an increase in the resource rent will, however, imply that the consequences of free riding become more serious and thereby leave greater room for stable solution. Generally speaking, this implies that climatic changes with a positive effect on the resource rent make joint solutions more likely.

A reduction in oxygen concentration may result in fish migration to more oxygen rich areas. This can lead to a concentration of fish in certain areas, which can even increase the catch per unit of effort, even if the biomass is reduced; such a scenario could have negative effects both from the reduced oxygen concentration and from the increased fishing mortality. The effect from changes in oxygen and salinity on the management and stability of joint action is an area for further research and requires a model including a spatial relationship.

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