ROBUSTNESS OF SHARING RULES UNDER CLIMATIC CHANGES - THE CASE OF INTERNATIONAL FISHERIES AGREEMENT

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ABSTRACT

Many international fisheries agreements involve sharing rules. These rules are normally stable rules, not contingent on shifts in the relative distribution or development of the resource. In the latest IPCC report, the most like future scenario is an increase in the global mean temperature, and most severely in high latitudes. <P>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. [14,15]). A more rigorous game theoretic analysis of sharing rules and their robustness with respect to especially economic parameters has been conducted in [12]. Their approach introduces a connection between cooperative games (sharing rules) and non-cooperative games (stability) and seems in particular suitable for a theoretic analysis of which type of sharing rules are robust. <P>Our contribution is to analyze the possibility of finding sharing rules that can cope with long run changes in the composition of the 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. <P>

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

INTRODUCTION

The newest report from IPCC [10] assesses that global average temperature will rise with about 1.2-5.8 degree over the next 100 years. Many international environmental treaties and international resource sharing arrangement will be affected by these climate changes. In particular international fish sharing arrangement 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. 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 international resource sharing arrangements. Our basic focus is on how the room for free rider stable solution changes when climate changes occur. Moreover, the results pinpoint on possible remedies for managing (that is, reduce) the instability of such arrangements due to climate change.

From a game theoretic point of view, when the joined benefit is increasing, then the free riding incentives normally increase as well.[a] This paper contributes by exploring the relation between the joined 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 shift such as global changes.

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)[b] and conservation of straddling fish stocks (fish that migrate between EEZs and the waters beyond)[c]. 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. [14] mostly (exclusively) analyses cases of highly migratory fish resources (such as the Northeast Pacific salmon, and the Tropical tunas. The main effect of (temporarily) climate changes is that the fish resource moves such that the premises the agreements rest on changes, making the agreement unstable.[d] [14,15] concludes on basis of a study of several commercial important shared fish 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 contributes to the dysfunction or even breakdown of existing cooperative arrangements.[e] 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 [21]. In the Baltic Sea until 2006 the allocation of TACs has, for individual species (cod, herring, sprat, salmon), also been based on fixed percentages [18] 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.
Among one of the main findings is that climatic changes increase the scientific uncertainty, on which basis most agreements rely on. This highlights the need for better information or the need for having a flexible management system that can cope with shifting environments.
In contrary to these papers, our paper provides a more rigorous game-theoretic approach, which we believe is necessary to reduce the uncertainty stemming from expected climate change. We adapt the case of Baltic cod fisheries. We find that this case carries lessons for many shared fisheries, where a trend in climate slowly changes the environmental conditions for the fish stocks.
The paper sets 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, hereunder also the singletons, are assumed to choose strategies that maximize their economic benefits over a time horizon of 50 years. The model explores how the stability of a grand coalition changes if an exogenous affect such as a climate change changes the biological settings of the fishery. By implementing our model we show that if a climate change adds value to the resource stock in form of increase in the size of the biomass or a larger fraction of mature fish, then other things equal, there is a larger room for stable joint solutions. If the contraire is true, for instance a reduction in the recruits per spawner, then there is less room for stability.
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 and the estimated scenarios. The last section concludes the paper.

STABILITY OF AGREEMENTS AND EXTERNALITIES

The classical approach of cooperative games is based on the fundamental assumption that 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 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 the stability is the way the benefits inside the cooperation are shared among players (the sharing rule). The classical theory of games in coalitional form is not fully satisfactory, as it ignores the possibility of externalities. This means that typically the action available to a coalition is assumed to be independent of the actions chosen by non-members [8]. Since this paper deals with extraction of a renewable resource by more 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 [17] and as a stability measure approach in [12], which includes the free rider values as threat points. This paper contributes to the literature by exploring the important connection between stability of management agreements in fisheries when the resource stock is subject to exogenous changes such as a climate change.

Requirements for a stable agreement

On a very general level, for an agreement in international society to be stable, [2] argues that an agreement must contain the following five elements in order to be stable. 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-participators should not exploit the agreement. Some of these five elements are addressed in our analysis. We do not explicitly consider these points, but with regards to internal stability, we say that stability of an agreement is increased, when the aggregate gain increases relative 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 is free riding and non-compliance.[f]

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.[g] The newest IPCC report [10] predicts a 1.2-5.8 degree increase over the next 100 years. Most generally, in specific geographically 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 the 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 the Baltic Sea cod [11]. An expected temperature increase affects both recruitment and size. Both directly, but also through the effect on salinity and oxygen content in the water, which also affects the fish resource. It is most likely that an increase in temperature reduces the level of oxygen, and to some extend, the salinity in the Baltic Sea.[h] The oxygen content is affected by changes in wind, changes in inflow of waters from North Sea and chances in temperature directly.[i] The content of salinity is mostly affected by changes in precipitation and changes in fresh-water runoff an inflow from the North Sea. Here again, the general prediction is that salinity content is likely to fall. The schematic overview over effects is shown in figure 1, where the notation in the last two boxes refer the coalition and free rider profits and stability of 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.

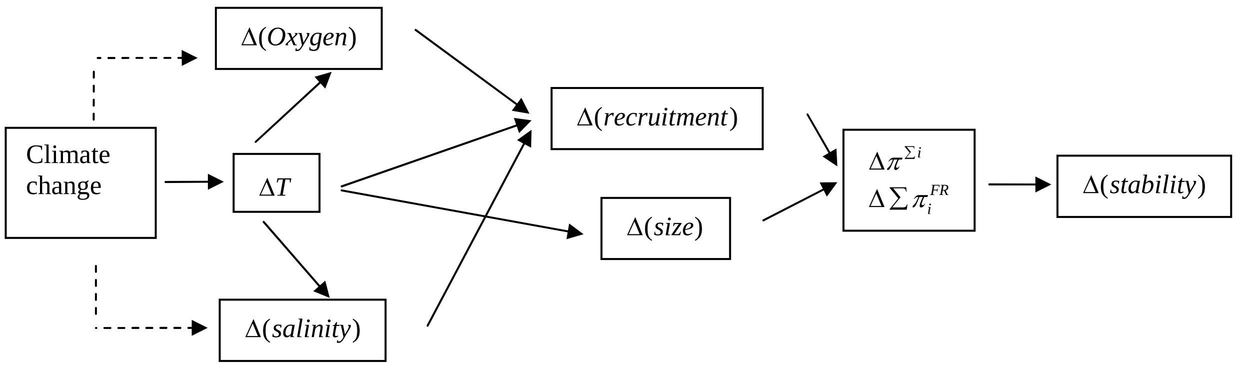


Figure 1. Schematic picture over how climate change affects stability in the Baltic Sea[j]

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:

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

The size of a representative fish with age *t* is the product of the annual increases ($\left(\alpha_i\left(T\right)\right)$) 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:

$$S_t = \left(1+\alpha\left(T\right)\right)^t \cdot S_0 \quad \text{(Eq. 2)}$$

It is generally asserted that $S_T^{'} > 0$ for all relevant T_t [13].

Finally, in the simulation we use weight (*W*) rather than size, and length (size) and weight are interconverted using a straightforward length-to-weight relationship: $W = 0.0104S^3$ [6].

Relation between recruitment and temperature

The recruitment-temperature relationship is more complex. Recruitment tends to increase with increasing 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 beyond 12°C in the future, the assumption is that the cod will disappear.[k] 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 variables 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 every 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:[l]

For $T \in [0;5]$, $E[R_t(T_t)]$ is mainly larger than zero

For $T \in [5,8;5]$, $E[R_t(T_t)]$ is close to zero (Eq. 3)

For $T \in [8.5;12]$ $E[R_t(T_t)]$ is mainly smaller 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.

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

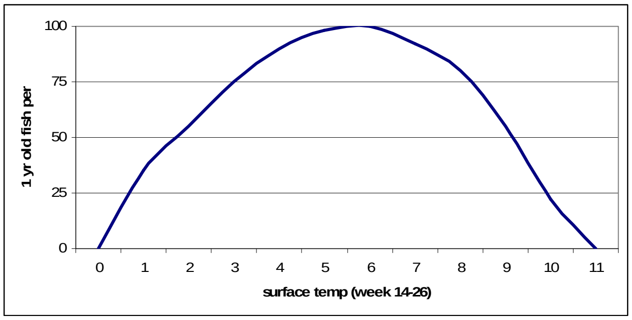


Figure 2a. Relation between number of 1 year old cod and the temperature [4]

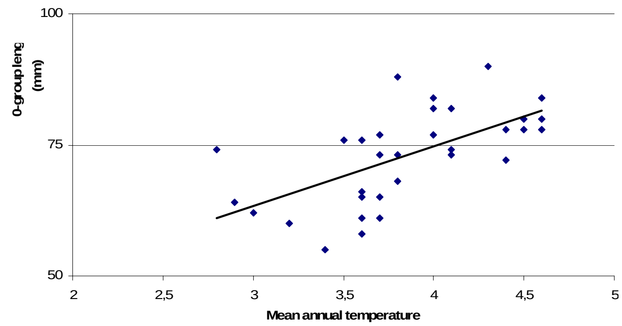


Figure 2b. Variation in 0-group cod length and annual mean Kola temperature during 1965-1997 [16].[m]

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.

THE MODEL

Basic relations

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 than smaller fish. The value (or better the biomass) is 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. We throughout 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.

The basic scenario is the simulation without a climate component. It corresponds to the one reported in [12].

The second scenario is the case, where climate change only affects the 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 the recruitment increases the 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 could always keep catches unaffected, in which case profits increase.

The third scenario is the case, where climate change only affects the 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 scenario 2 and 3 and implies a change in biomass from two sources namely an increase weight and a decrease in the 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 comparing 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:

$$\frac{\Delta[\pi^{\sum i} - \sum_i \pi_i^{FR}]}{\Delta T}, \qquad \text{(Eq. 4)}$$

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 cooperative solution is stable or not. To ensure stand-alone stability the following equation has to be positive [17].[n]

$$\pi^{\sum i} - \sum_i \pi_i^{FR} \qquad \text{(Eq. 5)}$$

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

The Baltic Sea

The Baltic Sea is a shared sea among 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 3 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).[o] All the parties exploiting the cod stock are members of the IBSFC who sets an agreement for the total allowable catches (TACs) for the fishery. Seemingly there is a coalition since TAC measures are agreed upon among all contracting parties in the IBSFC, but basically the TACs are allocated according to fixed distribution keys [18].

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 effect 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 [12]. The benefits from different coalitions and for free riders are calculated.[p] 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.

Description of the applied recruitment-temperature and weight-temperature relation

So far, we have been rather vague about how temperature exactly changes the recruitment. In order to make simulation, we need to operationalize the recruitment function. The basic scenario applies the parameter values given in [12].[q] In particular, initial values for stock weight are given by [9] 1998-estimates. The stock recruitment function follows an age-structured Beverton-Holt stock-recruitment relationship, identical to the one used by [9], defined as follows:

$$R_t = \frac{cSSB_{t-1}}{1+bSSB_{t-1}}, \qquad \text{(Eq. 6)}$$

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.[r] SSB_t is the spawning stock biomass in year t. The biological parameters of the stock recruitment relationship are summarized in table I.

Table I: Stock-Recruitment (B-H) Parameter Values

Parameter	Value
C	0.9814216
B	0.000002340

From [9].

We apply the weight-temperature relationship reported in [6]:

$$G = (\gamma_1 + \delta_1 \cdot T)\cdot W^{(\gamma_2+\delta_2\cdot T)}, \qquad \text{(Eq. 7)}$$

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 the paper give the following expression

$$G = (0.42\cdot T)\cdot W^{(-0.19-0.02\cdot T)}. \qquad \text{(Eq. 8)}$$

The above expression is only valid for $W< 5000$.

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., [22]. 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 average annual growth rates, which we apply for each year of the fish. Since the baseline weights ($W_t^{T_0}$) are known, we need only the following expression:

$$W_t^{T_N} = \prod_{i=0}^{t}\left(1+\alpha^{T_N/T_0}\right)W_t^{T_0}, \qquad \text{(Eq. 9)}$$

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 and α^{T_N/T_0} is the additional growth at T_N compared to base line growth at T_0, finally, $W_0^{T_0}$ 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 500 g fish when 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 temperature is increasing from 4 to 7 degrees. Table II summarizes results from the calculations.

Table II: 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 II we can conclude that within the temperature range we are working there is an average growth in the stock size. What should be remarked is, however, that it is not a linear growth, within the range we are working; the maximum percentage growth is found for 6-7ºC. It should be noted that there are several problems (critical 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 don't see this as a problem, except that this approach underestimates the growth, since the growth is continuous every day. This also has as effect that in the high growth scenario, the time until W is increased 500 is smaller, which also underestimates the true growth. To compensate for these underestimates and for sensitivity reasons we have also estimated results for growth larger than what is calculated in table II.

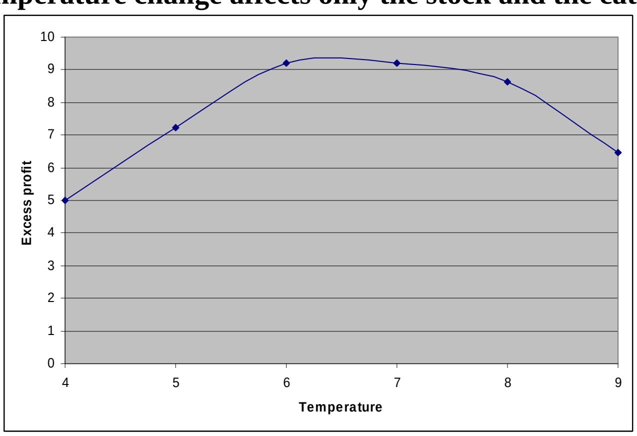
These *second* scenarios estimate the consequences of a reduction in the maximum recruits per spawner, *c*, ion the Beverton-Holt stock recruitment function. Initially the parameter *c* is close to 1, the consequences of a reduction in *c* to 0.7, 0.5 and 0.3 are estimated since climatic changes might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

The third scenarios with increment in size deal with three different levels of increases, 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:

$$SW^a_{T_N} = SW^a\left(1+\alpha^{T_N}\right)^{(a-1)}$$
$$CW^a_{T_N} = CW^a\left(1+\alpha^{T_N}\right)^{(a-1)} \qquad \text{(Eq. 10)}$$

where $SW^a_{T_N}$, is the stock weight for cohort *a* after the increase, $CW^a_{T_N}$ 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, we can determine how the 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 form a grand coalition compared to the free rider profits, when a temperature change affects only the stock and the catch weight.



The *fourth* scenarios combine the effects of the second and the third scenario. It illustrates the uncertainty of how climatic changes affect fish stocks. Scenarios exploited here combines worst-best scenarios from the two above 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.

Estimation Results

The uncertainty of what happens with climate changes is captured by setting up 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 III.

Table III: Results from estimations for different scenarios

		$\Pi^{123} - \sum_{i=1}^{3} \Pi_i^{FR}$ In 10^9 Dkr.	$\frac{\Delta[\Pi^{123} - \sum_{i=1}^{3} \Pi_i^{FR}]}{\Delta T}$ 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 increase because the consequences of free riding (the negative externality) become more serious. From the literature [7] 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 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. Further 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 is illustrated by the scenarios where the recruits per spawner are reduced. The particular size of the numbers in table 2 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 increases 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 contraire happens, namely a relative 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.

Sensitivity and Robustness Analysis

The scenarios included in the paper give in itself a picture of robustness and sensitivity of the model since estimates are given for different parameter values in each scenario. Therefore this section does not test the sensitivity for the parameters already discussed but instead test the robustness if other parameter values are changes. It is tested what happens if the fraction mature of each cohort are increased or if the maximum recruit per spawner for high biomass level (increase in *b* parameter in Beverton-Holt function). 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 is the change decreases the value of the biomass there is less room for a stand-alone stable solution.

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 3 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 two first mentioned scenarios have countervailing affect on the biomass. Within these scenario the likelihood for stably 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.

Several paper conclude, based on case studies, that climatic changes and climatic variability implies 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 of climatic changes. We show that when the value of the stock increases, there will we a larger room of making a stable agreement. That is if climatic changes increase the resource rent then there is more room for stand-alone stable agreements. These conclusions are subject to the uncertainty about actual climatic changes and following consequences for recruitments and changes in stock size. The uncertainty becomes particular clear in our last scenario that 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 leaving a larger 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 though the tough the biomass is reduced; such a scenario could have negative effects both from the reduced oxygen concentration and form 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.

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[a] See [2] for this point in international environmental agreements.

[b] Some of the more important are: EU-Norway fishing agreement of 1980 with shared stocks, Denmark, Iceland, Norway concerning capelin stock in between Greenland, Iceland and Norway, Norway-Russia in Barents sea (with 3

party access), Australian-Papa New Guinea (shared stock in Torres Strait), Baltic Sea Fisheries commission concerning shared stocks in Baltic Sea, Pacific Salmon agreement between US and Canada.

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

[d] The conclusions are also present in the following quote from abstract in [14], 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”.

[e] 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 [15].

[f] 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 will free riding or non-compliance be.

[g] Also changes in the presence and strength of wind (-fields) are expected in response to climate changes, which also affects fish stocks. For cod: The biomass of zooplankton, the main food for larval an juvenile fish, is generally greater when temperature is increasing 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 vulnerable stages decreases with higher temperature.

[h] 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 on the early life stages of cod (quotation from [20], page 4).

[i] This is due to increased oxygen-consuming demineralisation of organic materials, but also because increasing water temperature reduces oxygen resolution [29].

[j] A more thorough picture can be found in [19].

[k] It, however, also shows the uncertainty. Moreover, regional factors might influence the correlation, such that it not necessarily can be used in other regions. [5] present data from Barents Sea showing a highly positively correlation between 0-group cod length and annual mean (water) temperature.

[l] Conclusions from [3,4].

[m] The functional form of the linear relationship is $S(T) = 11.364T + 29.188$, $R^2 = 0.3782$.

[n] In our paper we only deal with three players which explain why we are considering benefits from singleton free riders and not from smaller coalition’s free riding.

[o] IBSFC as an organisation ceased to function from January 2006.

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

[q] Only changes to this model will be highligthed here.

[r] The stock-recruitment estimated by ICES assumes that recruits are not entering the population before age 2, therefore the SSB is lagged two years in the Beverton-Holt recruitment function applied by [9]. For simplicity reason, 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 reasonable monotone on every two successive years.