SCOPE AND COMPATIBILITY OF MEASURES IN INTERNATIONAL FISHERIES AGREEMENTS*

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Abstract

We set up a model which captures the spatial dimension of international fisheries in legal (i.e. internationally accessible high seas versus state-owned exclusive economic zones) and biological (i.e. various intensities of fish migration between zones) terms. We compare the success of regional fishery management organizations (RFMOs) for the first-best and two alternative management scenarios, related to restrictions regarding the scope and compatibility of measures. While the performance of a given RFMO declines in the presence of these alternative management practices, participation might improve as free-riding becomes less attractive and the overall net effect may well be positive.

JEL References: C72, F53, H87, Q22

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1. Introduction

Managing global and international commons requires voluntary international cooperation due to the absence of a supranational institution that could enforce a cooperative management strategy (Barrett 1994). While, in general, a tragedy of the commons is not inevitable, internationally shared fish resources seem to be particularly vulnerable to overexploitation. In an attempt to address this problem, state-owned property rights have been established under the legal regime of the United Nations Convention on the Law of the Sea (UNCLOS; see UN 1982). According to Articles 56 and 57 of the Convention, every coastal state has the right to establish an Exclusive Economic Zone (EEZ), adjacent to its territorial waters, extending 200 nautical miles into the sea, in which it exercises sovereign rights regarding the management of all marine resources. Beyond the EEZs, in the high seas, the open access regime persists (as long as no further measures are taken, i.e. resources are subject to the exploitation by all nations (Art. 87).

Despite this large-scale allocation of property rights, many commercially valuable fish stocks are still overexploited because they either occur in the high seas and/or migrate through more than one jurisdictional area.[1,2] Addressing this problem requires a comprehensive and consistent international management of shared fish stocks. International marine law recognizes this need for international coordination and cooperation. Articles 63 and 64 of the UNCLOS call for a cooperative management of straddling and highly migratory fish stocks, either directly through bilateral negotiations or through the development of regional fisheries management organizations (RFMOs).

1 For a documentation of the state of internationally shared fish resources, see FAO (2010), Maguire et al. (2006) and McWhinnie (2009).

2 The common classification of shared fish stocks (cf. Munro et al. 2004, p. 3) is as follows: *transboundary stocks* inhabit (or cross) the EEZs of two or more coastal states, *highly migratory stocks* are to be found both within the EEZs and the adjacent high seas and are highly migratory in nature, s*traddling stocks* also cover both EEZs and the high seas but are more stationary, *discrete high seas stocks* occur only in the high seas. Examples are provided in Table III below.

This call for cooperation is repeated by the UN Fish Stocks Agreement in 1995 (UN 1995), which deals explicitly with the conservation and management of straddling and highly migratory fish stocks.[3]

The success of RFMOs essentially depends on two dimensions.[4] The first dimension relates to how RFMOs can control free-riding of non-members. This is normally difficult as participation in RFMOs is voluntary. While there is a general consensus that unregulated fishing is morally reprehensible, it has not, in the past, been entirely clear what members of an RFMO can do to suppress it. Therefore, we assume that states which decide against membership in an RFMO cannot be prevented from harvesting.[5]

The second dimension relates to the management within an RFMO. While there is a broad consensus in the international community that the management of shared fish stocks requires a cooperative approach, the details have been controversial during the negotiations preceding many fishery agreements. The undisputed sovereignty of coastal states with respect to the management of intra-EEZ resources obviously conflicts with the aim of a consistent management of shared fish stocks across the entire geographical area of their occurrence. The UNCLOS in 1982 calls for cooperation "both within and beyond the exclusive economic zone" (Art. 64 (1)) in the case of highly migratory species, whereas for straddling stocks Art. 63(2) only requires a cooperative management in the high seas. The UN Fish Stocks Agreement in 1995 restates this distinction (Art. 7(1)) and emphasizes both the sovereignty of coastal states regarding intra-EEZ fishery

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3 There are currently 20 RFMOs in force as for example the Northwest Atlantic Fisheries Organization (NAFO) and the North East Atlantic Fisheries Commission (NEAFC). For an overview, see for instance Munro et al. (2004) and FAO (2014), online.

4 Reports that seriously and consistently measure the effectiveness of RFMOs are scarce. Some evidence is gathered for instance in High Sea Task Force (2006) and Lodge et al. (2007). As Willock and Lack (2006), p. 32, write: "There appears to be some reluctance to, or at least nervousness about, establishing a standard set of performance indicators against which RFMOs might be held accountable and their performance compared." From completed self-assessment reports (e.g. NEAFC 2006, ICCAT 2009 and IOTC 2009) a rather pessimistic picture emerges.

5 The legal basis and the implications of giving up this assumption are briefly discussed in section 7.

management but also the importance of the compatibility of conservation measures at the same time (Art. 7(2)). Accordingly, most currently existing RFMOs confine the area of actual management to the high seas, but call for a compatibility of intra-EEZ and high seas management measures, though they remain vague how this compatibility shall be achieved.[6]

A good representative example for this vagueness of regulatory power is the herring fishery in the North East Atlantic, which is shared by Norway, Iceland, the Russian Federation, the European Union, the Faroe Islands and Greenland, accounting for an annual catch of more than 1.6 million tons in 2009. The RFMO in charge of managing this stock, the North East Atlantic Fisheries Commission (NEAFC), states the "long-term conservation and optimum utilization of the fishery resources in the Convention Area" (Art. 2 NEAFC Convention) as its objective. Although the Convention Area comprises both areas within and beyond national jurisdiction, NEAFC's regulatory power is limited to the high seas in recognition of the sovereign rights of coastal states within EEZ boundaries (Art. 5(1)).[7] A consistent management is defined as one that respects the management measures adopted by coastal states within the areas under their national jurisdiction (Art. 5(2)). Similarly vague and contradictory provisions are part of the

6 The ambiguity inherent in Art. 7 of the UN Fish Stocks Agreement in 1995 leaves room for several interpretations. While Oude Elferink (2001) argues that it should be interpreted as favouring neither coastal states nor RFMO management authorities, Molenaar (2005) clearly supports the position of many coastal states, which claim priority and sovereignty for coastal fisheries management. In order to avoid conflicts, some RFMOs simply ignore this issue. For instance, a recent performance review criticized that the International Commission for the Conservation of Atlantic Tunas (ICCAT) „*has not taken any measure aimed at ensuring the compatibility between conservation and management measures adopted by a coastal State with respect to the areas under its jurisdiction and those adopted by ICCAT*" (Hurry et al. 2008, p. 16).

7 Regarding fishing in the EEZ of a member state, the NEAFC Commission has only limited influence. First, it can only make recommendations if the coastal state in question requests this. Second the coastal state has to approve the recommendations in order for them to become effective (Art. 6(1)). Similarly, the regulatory power of the Western & Central Pacific Fisheries Commission (WCPFC) is limited as 80% of the tuna catch is within the EEZs of its members.

conventions of many RFMOs, creating a constant source of conflict between RFMO member states. For example, a recent performance review of the North Atlantic Fisheries Organization (NAFO) criticized that "the language used [in the NAFO Convention] does not create an obligation on either the [NAFO] Commission or coastal State to ensure consistency in their measures" (NAFO 2011, p. 22). Consequently, conflicts arise such as in 1999, when the EU accused Canada for intra-EEZ cod fishing being incompatible with conservation efforts established by NAFO (Oude Elferink 2001).

Obviously, a social planner would implement an optimal fishery management scheme. Technically speaking, he would maximize the aggregate economic rent across all zones, taking into account linkages across zones through migration. Such an optimal management scheme for resources with spatial externalities (e.g. via migration) has been extensively studied in spatial models (e.g. Costello and Polasky 2008 and Sanchirico and Wilen 1999). However, in internationally shared fisheries, there is no institution with the enforcement power of a social planner. On the one hand, participation in an RFMO is often incomplete as participation is voluntary and cannot be enforced. On the other hand, RFMO members may not implement an optimal strategy, for instance because they hold different views regarding what constitutes a consistent fishery management or because they do not want to give up their sovereignty to control fishing in their EEZs. It is the aim of this paper to evaluate the success of RFMOs in such a strategic setting and under the restriction that RFMOs have to be self-enforcing. In particular, we are interested in comparing the performance of RFMOs implementing a first-best strategy to those with second-best strategies (as defined in the model developed below).

In a strategic setting, the outcome of such a comparison is not obvious for at least two reasons. First, due to strategic interaction between fishing nations, either as an RFMO member or non-member, what is optimal at the individual level does not necessarily have to be optimal at the aggregate level and vice versa. Second, even if a departure from a first-best management strategy directly negatively impacts on economic rents, this may be compensated indirectly by higher participation in an RFMO. A less ambitious management strategy may buy more participation, which may improve the overall performance of an RFMO. Whereas it is straightforward to define an optimal or first-best management, the possibilities of second-best designs are numerous. In order to test the robustness of our conclusions, we will consider two versions of second-best management strategies related to what we call the scope and the compatibility of measures.

The issue at stake requires an approach that captures two essential features of international fisheries simultaneously. First, we have to set up a bioeconomic model, which captures different geographical areas (high seas and EEZs) and the migration of fish stocks across zones. Second, we require a coalition formation model which tests for stability of RFMOs. In the literature on fishery economics, such an integrated approach is missing so far. The first aspect is dealt with in several papers considering the exploitation of a migratory fish stock by two or more competing fishing nations (e.g. McKelvey et al. 2002, Hannesson 1997, Naito and Polasky 1997, and Arnason et al. 2000). These papers typically consider the Nash equilibrium outcome in a competitive game and demonstrate its inefficiency by contrasting it with the outcome of a fully cooperative management scheme. They do not, however, examine the stability and success of coalitions, and if so, they only test for stability of the grand coalition but not of partially cooperative agreements. Also on the second aspect there exists an extensive literature on international fishery coalitions which can be broadly divided into two categories (for an overview, see Lindroos et al. 2007). Most of the early papers apply *cooperative* game theory to examine the implications of various sharing rules such as the Shapley value under full cooperation (e.g. Kaitala and Lindroos 1998 and Duarte et al. 2000). This approach, however, does not allow studying the impact of free-riding explicitly. This requires concepts from *non-cooperative* coalition theory, first applied by Pintassilgo (2003) to the analysis of international fisheries. In a similar paper, Pintassilgo and Lindroos (2008) conclude that the non-cooperative Nash equilibrium is the only stable outcome whenever the number of fishing nations exceeds two. However, these papers confine their analysis to one zone; hence migration does not matter. Our work extends Finus et al. (2011), who incorporate different geographical zones and migration into the analysis of international fishery coalitions, by considering the impact of alternative management strategies.

Our paper is organized as follows. Section 2 describes the bioeconomic model, the coalition formation model and the first-best and two alternative fishery management strategies. Section 3 outlines the model and parameter specifications, details our solving procedure and highlights the applications of our model. Sections 4 to 7 discuss our results under various management scenarios and section 8 concludes.

2. The Model

2.1 Preliminaries

The analysis of cooperation in international fisheries requires concepts from biology in order to describe the biological processes of the fish stock (e.g. growth and migration patterns), has to take into account the legal framework of international marine law, and should capture the essential features of economic behaviour of the protagonists in the "fishery game". The biological part is based on the classical Gordon-Schaefer model (Gordon 1954 and Schaefer 1954) which has been frequently used to analyse the steady state of an exploited (fish) resource (for an introduction, cf. Clark 2005). The economic and behavioural part is based on the single coalition open membership game due to d'Aspremont et al. (1983) which has been frequently applied in the literature on international environmental agreements (e.g. Carraro 2000 and Finus 2003 for surveys).

2.2 The Biological and Spatial Dimension

We assume that a given number of fishing nations N exploit a shared fishery resource which is characterized by an intrinsic reproduction process. The steady state of the fish stock in the classical Gordon-Schaefer-model is described by the following equation:

$$\frac{dX}{dt} = G(X) - H(X, \boldsymbol{E}) = 0 \ . \tag{1}$$

Equation (1) states that in the steady state, growth G and harvest H are balanced such that the stock X remains constant over time. For intrinsic growth, it is usually assumed that growth requires an initial population $\left(G\left(X=0\right)=0\right)$, it is positive as long as the carrying capacity k has not been reached $\left(G\left(0<X<k\right)>0\right)$ and it stops at the carrying capacity k of the system $\left(G\left(X=k\right)=0\right)$. Total harvest depends on the stock X and the vector of individual fishing efforts $\boldsymbol{E}=\left(E_1,...,E_N\right)$.

In order to capture the fact that the traditional open access and laissez-faire regime has been replaced by the legal framework defined by the UNCLOS in 1982, we have to extend the classical model by partitioning the sea into various zones: the high seas, abbreviated HS, i.e. the "common property" where all nations are allowed to fish, and the exclusive economic zones, abbreviated EEZ_i, i.e. the "private property" where only coastal state i controls fishing. We denote the entire carrying capacity of the system by k_{tot}, assuming that a share α of this capacity is subject to access by all fishing nations and define:

$$k_{HS}=\alpha k_{tot} \text{ and } k_{EEZ}=\frac{1-\alpha}{N}k_{tot} \tag{2}$$

which implies that the larger α the larger will be the publicly compared to privately accessible part of the fish stock. In our context, players are sovereign countries engaging in fishing, i.e. coastal states, each controlling an EEZ with exclusive fishing rights, but they have also access to the high seas.[8] The vector of fish stocks, $\boldsymbol{X}=\left(X_1,...,X_N,X_{HS}\right)$, describes the population in each zone. The modified steady state condition (1) then reads:

$$\frac{d\boldsymbol{X}}{dt}=\boldsymbol{G}\left(\boldsymbol{X}\right)-\boldsymbol{H}\left(\boldsymbol{X},\boldsymbol{E}\right)+D\boldsymbol{X}=0 \tag{1'}$$

[8] A coastal state can also issue fishing licences for its EEZ to other states. We assume for simplicity that in each EEZ only the respective coastal state engages in fishing.

where the term DX accounts for the migration of fish stocks across zones with D a diffusion matrix which is explained in more detail below. The components of the growth vector $\boldsymbol{G} = (G_1, ..., G_N, G_{HS})$ describe intrinsic growth in each zone. Similarly, harvesting in each zone is defined by the harvest vector $\boldsymbol{H} = (H_{EEZ,1}, ..., H_{EEZ,N}, H_{HS})$ which depends both on the vector of stocks, $\boldsymbol{X}$, and the vector of efforts, $\boldsymbol{E} = \left(E_{EEZ,1}, ..., E_{EEZ,N}, E_{HS,1}, ..., E_{HS,N}\right)$. Note that each fishing nation i has two strategic variables, its fishing effort in its own EEZ, $E_{EEZ,i}$, and the fishing effort in the high seas, $E_{HS,i}$. Due to the migratory behaviour of fish stocks, harvest from each zone generally depends on all fishing efforts.

2.3. The Economic Dimension

2.3.1 Introduction

Within the framework of international fisheries, each fishing nation has to decide whether to join an RFMO or to remain outside, and it has to choose the level of fishing effort for its fleet. Cooperation among a group of players corresponds to the establishment of an RFMO with the purpose of managing and conserving the fish stocks jointly. Participation in an RFMO is open to all nations as reflected by Article 8(3) of the UN Fish Stocks Agreement in 1995. Moreover, participation is voluntary and states, which decide against membership in an RFMO, cannot be prevented from harvesting (see footnote 5).

From the set of coalition formation games discussed in the economic literature (e.g. Bloch 2003 and Yi 2003), we chose the single coalition open membership game as captures open and voluntary RFMO membership as described above. In the first stage, players decide upon their membership. Those players that join the RFMO form the coalition and are called members or signatories; those that do not join are called non-members or non-signatories and act as singletons. The decisions in the first stage lead to a coalition structure (i.e. partition of the set of all players) $\left\{S, \mathbf{1}_{(N-n)}\right\}$, where S denotes the coalition, the set of coalition members, comprising n members and $\mathbf{1}_{(N-n)}$ is the vector of

$N-n$ singletons. Given the simple structure of the first stage, a coalition structure is fully characterized by coalition S.

In the second stage, players choose their economic strategies, which are fishing efforts in our bioeconomic model. The standard assumption is that the coalition members cooperate among each other, maximizing the aggregate payoff to the coalition whereas all non-members maximize their individual payoffs. The simultaneous solution of these maximization tasks leads to an equilibrium vector of fishing efforts $\boldsymbol{E}^* = \left(E^*_{EEZ,1},...,E^*_{EEZ,N},E^*_{HS,1},...,E^*_{HS,N}\right)$ and individual economic payoffs from fishing in the own EEZ and the high seas, respectively:

$$\Pi^*_{EEZ,i}\left(\boldsymbol{E}^*\right) = pH_{EEZ,i}\left(\boldsymbol{X},\boldsymbol{E}^*\right) - C_i\left(E^*_{EEZ,i}\right) \text{ and } \Pi^*_{HS,i}\left(\boldsymbol{E}^*\right) = pH_{HS,i}\left(\boldsymbol{X},\boldsymbol{E}^*\right) - C_i\left(E^*_{HS,i}\right) \quad (3)$$

where p is the (exogenously given) fish price and $C_i\left(\cdot\right)$ denotes player i's cost function. Note that all stocks and therefore payoffs depend on the entire vector of fishing efforts (i.e. $\boldsymbol{X} = \boldsymbol{X}\left(\boldsymbol{E}^*\right)$) due to the process of migration that links the various fishing grounds. For notational convenience, we will omit the arguments in the payoff functions subsequently.

In the following, we have a closer look at the two-stage game, which is solved backward. Our main focus in this paper is related to the second stage. That is for a given coalition in the first stage, we consider not only the standard assumption about the choice of fishing efforts but also two alternative assumptions in the second stage. We are interested how different fishery management strategies affect the overall outcome of the game. The outcome is not trivial for at least three reasons. Firstly, the impact on second stage outcomes is not obvious because RFMO-members and non-members interact strategically. Secondly, second stage outcomes affect membership in the first stage. Thirdly, the overall performance of an RFMO depends on both stages. For instance, a lower performance in the second stage may be compensated by higher membership in the first stage.

2.3.2 Second Stage of the Game: Choice of Fishing Efforts under the Standard Scenario

The standard scenario in the literature assumes that each player, including the coalition of signatories as a kind of meta-player as well as all non-signatories as singletons, maximizes an objective function comprising payoffs obtained from fishing in the high seas and from the exclusive economic zones.

Non-signatories: $$\max_{(E_{EEZ,j},E_{HS,j})} \Pi_{EEZ,j} + \Pi_{HS,j} \quad \forall\ j \notin S \tag{4}$$

Signatories: $$\max_{(E_{EEZ,i},E_{HS,i})} \sum_{i \in S} \left[\Pi_{EEZ,i} + \Pi_{HS,i} \right] \quad \forall\ i \in S \tag{5}$$

The difference between non-signatories and signatories is that the former maximize their individual payoff whereas the latter maximize the aggregate payoff across all coalition members. Hence, equilibrium fishing efforts form a Nash equilibrium in a game between non-signatories and signatories. This is sometimes called a coalitional Nash equilibrium in order to distinguish it from an ordinary Nash equilibrium with which it coincides if coalition S is empty or comprises only one player. Moreover, if coalition S comprises all players, $S = \{1,...,N\}$, the coalitional Nash equilibrium corresponds to the socially optimal fishing vector. Hence, the entire range from Nash equilibrium to socially optimal fishing efforts can be captured with this approach by considering various coalitions that have formed in the first stage.

2.3.3 Second Stage of the Game: Choice of Fishing Efforts under Alternative Scenarios

Based on the analysis of international fisheries agreements (e.g. NAFO 2004, NEAFC 2007 and ICCAT 2007) and secondary literature on international marine law (e.g. Oude Elferink 2001 and Molenaar 2005), we consider two alternative scenarios as particularly relevant in practice (see also the discussion in the introduction). Clearly, formalizing this in a model implies a stylized representation of reality.

Alternative Scenario 1: Restricted Scope of Measures

As pointed out by Molenaar (2005) and Oude Elferink (2001), many coastal states are unwilling to give up their national sovereignty with respect to intra-EEZ fishery management. Moreover, as mentioned in the introduction, the sovereignty of coastal states is commonly recognized as undisputable and the legal framework in international fisheries is not always clear about the scope of measures required in RFMOs. In order to capture the possibility of a restricted scope of measures in a systematic and simple way, we replace conditions (4) and (5) by the following three conditions:

Non-signatories: $$\max_{\left(E_{EEZ,j},E_{HS,j}\right)} \Pi_{EEZ,\,j} + \Pi_{HS,\,j} \quad \forall\, j \notin S \tag{6}$$

Signatories: $$\max_{E_{EEZ,i}} \Pi_{EEZ,\,i} + \Pi_{HS,\,i} + \gamma \sum_{m \in S,\, m \neq i} \left(\Pi_{EEZ,\,m} + \Pi_{HS,\,m} \right) \quad \forall\, i \in S \tag{7}$$

$$\max_{E_{HS,i}} \sum_{i \in S} \left[\Pi_{EEZ,\,i} + \Pi_{HS,\,i} \right] \quad \forall\, i \in S \tag{8}$$

where $\gamma \in [0,1]$ denotes the *scope parameter*. Condition (6) describes non-signatories' non-cooperative behaviour, which is unaffected by the scope of measures. Accordingly, conditions (4) and (6) are identical. In contrast, condition (7) captures the idea that the decision about intra-EEZ fishing may remain with the coastal state even if a country decides to become a member of an RFMO. Hence, γ describes what we call the scope of measures, i.e. γ parameterises the extent to which the RFMO can control fishing in the EEZs. Condition (8) reflects the assumption that the coalition decides upon the fishing efforts in the high seas.

If $\gamma = 0$, the RFMO does not control fishing in the EEZs of its members. At the other extreme, $\gamma = 1$ the RFMO fully controls fishing in the EEZ of its members and, accordingly, condition (7) and (8) merge into condition (5). Any value of γ between these two extreme values allows us to systematically analyse different degrees of controlling EEZ fishing by the RFMO. Hence, γ can also be interpreted as different degrees of enforcement of RFMO-rules in member states' EEZs.

In order to fully appreciate the difference between alternative scenario 1 and our next alternative scenario 2, which we call restricted compatibility of measures, it is important to point out the following features. In (7) RFMO members are fully aware that fishing in their own EEZ will affect their payoff derived from the high seas and, vice versa; in (8) they understand that fishing in the high seas will impact on their EEZ stocks and hence payoffs. The same holds for non-members, as captured by (6). In other words, all countries are fully aware of the linkages between zones through migration. This is different in the next scenario.

<u>Alternative Scenario 2: Restricted Compatibility of Measures</u>

The second scenario captures the idea of restricted incompatibility of measures. This acknowledges the fact that though compatibility of measures is called for in many international fisheries agreements, it is usually insufficiently implemented, especially if a fishing nation puts the management of its own intra-EEZ and high seas fishing activities under the control of different national authorities (see Arbuckle et al. 2006, p. 36). A simple way of modelling this is to assume that the coalition as well as non-signatories only partially account for their payoffs from the high seas when determining optimal fishing efforts in the EEZs and vice versa:

Non-signatories:

$$\max_{E_{EEZ,j}} \quad \Pi_{EEZ,j} + \lambda \Pi_{HS,j} \quad \forall j \notin S \tag{9}$$

$$\max_{E_{HS,j}} \quad \Pi_{HS,j} + \lambda \Pi_{EEZ,j} \quad \forall j \notin S \tag{10}$$

Signatories:

$$\max_{E_{EEZ,i}} \quad \sum_{i \in S} \Pi_{EEZ,i} + \lambda \sum_{i \in S} \Pi_{HS,i} \quad \forall i \in S \tag{11}$$

$$\max_{E_{HS,i}} \quad \sum_{i \in S} \Pi_{HS,i} + \lambda \sum_{i \in S} \Pi_{EEZ,i} \quad \forall i \in S \tag{12}$$

The *compatibility parameter* $\lambda \in [0,1]$ parameterises the degree of compatibility of measures. Condition (9) and (10) define the maximization behaviour of non-signatories whereas condition (11) and (12) refer to the behaviour of coalition members. If $\lambda = 0$, players fully ignore the need for compatible measures. At the other extreme, $\lambda = 1$ corresponds to fully compatible measures, i.e. conditions (9) to (12) collapse into conditions (4) and (5), our standard scenario. Non-signatories are assumed to implement always the same degree of compatibility as signatories for simplicity.[9]

2.3.4 Conclusion about the Second Stage

Viewed together, regardless whether we consider the standard or alternative management scenarios in the second stage, the solution of the respective first order conditions (together with the steady-state conditions eq. (1') of the biological equilibrium) leads to an equilibrium vector of fishing efforts which allows to determine steady state stocks (eq. (1')) and equilibrium payoffs (eq. (3)).[10] Each scenario can be viewed as a clear instruction how to choose fishing efforts in the second stage, given some coalition S has formed in the first stage. Hence, in order to simplify the following notation, we can replace $\Pi_i^*(E^*) = \Pi_{EEZ,i}^*(E^*) + \Pi_{HS,i}^*(E^*)$ by $\Pi_i^*(S) = \Pi_{EEZ,i}^*(S) + \Pi_{HS,i}^*(S)$ or simply $\Pi_i^*(S)$.

2.3.5 First Stage of the Game: Choice of Membership

For the first stage, we use the equilibrium concept of internal and external stability, i.e. a coalition S is considered to be stable if it satisfies the following two conditions:

9 A reviewer pointed out that it would be plausible to assume higher values of λ for RFMO-members than non-members. We briefly report on this alternative assumption in section 6, footnote 19.

10 This implies to compute ex-post payoffs. This keeps with the tradition of other papers modelling different economic behaviour through different objective functions, but using the "true" welfare function for evaluation. See for instance Finus and Maus (2008) and Hoel (1991).

Internal Stability

No member $i \in S$ *finds it profitable to deviate, i.e. the gain* G_i *from leaving the coalition is non-positive:* $G_i := \Pi_i^*(S \setminus \{i\}) - \Pi_i^*(S) \leq 0 \;\; \forall i \in S$.

External Stability

No non-member $j \notin S$ *finds it profitable to join the coalition, i.e. the gain* Q_j *from joining the coalition is non-positive:* $Q_j := \Pi_j^*(S \cup \{j\}) - \Pi_j^*(S) \leq 0 \;\; \forall j \notin S$.

Note that the incentives G_i and Q_j depend on the coalition structure, the scope and compatibility parameters γ and λ as well as other parameters of the model (see section 3). The grand coalition is externally stable by definition as there is no outsider left that could join the coalition. Moreover, the coalition structure comprising only singletons is stable by definition, which ensures existence of a stable coalition structure. This follows from the fact that the singleton coalition structure can be supported as an equilibrium if all players announce not to be a member of the coalition, i.e. $S = \emptyset$, and hence a single deviation by one player will make no difference.

3. Model Specification, Solving Procedure and Applications

3.1 Preliminaries

In general, solving the second stage of the game requires solving a system of $3N+1$ equations ($2N$ economic FOCs and $N+1$ biological steady-state equations) for N optimal intra-EEZ efforts $E_{EEZ,i}$, N optimal high seas efforts $E_{HS,i}$ and $N+1$ steady-state stocks $(X_1,...,X_N,X_{HS})$. As optimal efforts in the second stage of the game depend on stock levels and vice versa, they all have to be determined simultaneously. Obviously, any solution will depend on the specification of the functional relationship between stocks, efforts and payoffs. That is, we have to specify growth, harvest and cost functions and define a dispersal matrix, which describes the migration process. This is done in subsection 3.2. Due to migration, the model is significantly more complex than the standard Gordon-Schaefer model. Therefore, generally, we have to rely on numerical simulations of which the underlying assumptions are described in subsection 3.3. Only in a few (uninteresting) cases can analytical results be obtained, but these are those cases where alternative management strategies do not make a difference to the standard strategy. This will be explained in detail in section 3.4, together with applications of our model.

3.2 Functional Specification

The functional relationships underlying our model are summarized in Table I. It will be apparent that the specifications follow the mainstream assumptions in the literature.

[Table I about here]

The most commonly used *growth function* (Table I, first row) is of the logistic type where r_i denotes the intrinsic growth rate in zone i.

Regarding the *harvest function* (Table I, second row), we have to bear in mind that all countries are allowed to fish in the high seas whereas only coastal state i controls fishing in EEZ_i. As commonly assumed, (total) harvest depends linearly on (total) fishing efforts and stock densities, with q_i denoting the catchability coefficient, a measure of the technical efficiency of fishing fleet i.

Two aspects need to be considered when specifying the *migration process* (Table I, third row).[11] First, the *arrangement of zones* has to be specified, i.e. which zones are connected through diffusion. We choose an intuitive and symmetric arrangement of the $N+1$ zones: each EEZ is connected to two neighbouring EEZs and to the high seas. This represents a good first-order approximation for the geographical setting of many examples where an area of high seas is surrounded by coastal zones. A perfect match of this assumption is for instance the 'Banana Hole' in the Northeast Atlantic or the 'Donut Hole' in the Bering Sea (see Meltzer 1994).

[11] For an extensive discussion of our and alternative assumptions see Finus et al. (2011).

Second, we have to define what determines the *intensity of migration* between two neighbouring fishing grounds. We assume a density-dependent diffusion process, i.e. the strength of migration between neighbouring fishing grounds is given by the difference in stock densities (e.g. Armstrong and Skonhoft 2006, Sanchirico and Wilen 1999 and Sibert et al. 1998).[12] This ensures the conservation of biomass in the absence of harvest and growth, i.e. whatever leaves zone i for zone j arrives in zone j without any loss. The diffusion parameter d_{ij} is an indicator of the intensity of diffusion from zone i to zone j. Note that many different kinds of individual movement patterns, when aggregated, lead to density-dependent migration. This is also true for a random movement, which is sometimes also described as Brownian motion. It is also important to understand that in line with our focus on the long-term steady state in a fishery, our migration process approximates well long-term variations in the spatial distribution of biomass but would not be adequate to describe short- or mid-term movements of individual fish, as for instance spawning or feeding migration.

It is a common assumption in the literature on fishery management (Gordon 1954, Pezzey et al. 2000 and Sanchirico and Wilen 1999) that *costs* (Table I, fourth row) depend linearly on extraction efforts where c_i is the (constant) marginal cost of fishing effort of the fishing fleet of country i.[13]

3.3 Simulations

Simulations require the assumption of numerical values for the parameters of the model. Fortunately, a closer look at the system of equations reveals that results will depend on

[12] Sibert et al. (1998) point out that models based on density-dependent diffusion '*have a long history in animal ecology (Skellam 1951), and their potential application to fisheries population modelling dates back at least to Beverton and Holt (1957) and Jones (1959)*'.

[13] That is, fishing nations face a completely elastic supply curve of input. Assuming a strictly convex cost function in terms of efforts would not change our qualitative conclusions. Note that even for our assumption, cost functions are strictly convex and depend on stock-densities if expressed in terms of harvest levels.

only few parameters. The choice of parameter values follows good practice, covering (almost) the entire parameter space (under the assumption of interior solutions) as summarized in Table II.

[Table II about here]

First, note that in order to save on computational time, we concentrate on the case of three players ($N=3$), which, admittedly, is the minimum number of players for studying coalition formation but, as we will see, is already sufficient to obtain (qualitative) interesting insights into the incentive structure of cooperative arrangements. For $N=3$, we have to consider three possible coalition structures, namely the grand coalition, including all three countries, two-player coalitions, and the all-singletons coalition structure. Furthermore, we restrict the analysis to symmetric parameter values, both with respect to the biological and economic parameters.[14] Consequently, all possible two-player coalitions are equivalent with symmetric payoffs for coalition members, though they differ from the payoff of a non-member.

Second, note that all subsequent results only depend on what is commonly referred to as the 'inverse efficiency parameter' c/pqk_{tot} (see Mesterton-Gibbons 1993). Since the total carrying capacity k_{tot} just represents a scaling factor, it is normalized to 4 as there are four zones.[15] Moreover, we can normalize p and q to 1 and hence only vary c. Thus, a variation of the cost parameter c is, ceteris paribus, de facto a variation of the relation c/pq. Since prohibitive costs at which countries quit fishing are given by $c \geq 1$,

14 The assumption of symmetric players is widespread in the literature on coalition formation, not only on international environmental treaties but also in the context of other economic problems (see e.g. Bloch 2003, and Yi 2003 for an overview). For symmetric players, it is natural to assume an equal sharing of the coalitional payoff. Pintassilgo et al. (2010) deals with optimal transfer schemes in case of asymmetric RFMO members.

15 This is in line with the common normalization $k=1$ for the carrying capacity in articles that deal with only a single zone (e.g. Pezzey et al. 2000). In our model, assuming no diffusion between zones with $k_{tot}=4$ and setting $\alpha=0.25$ results in four isolated zones with carrying capacities $k_{HS}=k_{EEZ}=1$. See equation (2).

irrespective of the scenario of cooperation, we have $c \in [0,1]$. In our simulations, we consider the three values, $c \in \{0.25, 0.5, 0.75\}$. For the intrinsic growth rate r, we also consider three values, $r \in \{0.25, 0.5, 0.75\}$.[16]

For the diffusion parameter d our simulations cover the range $d \in [0 .. d_{max}]$ with the upper bound $d_{max} = 1.28$ that approximates well the limit $d \to +\infty$.[17] With respect to α, we cover the whole range $\alpha \in [0,1]$, with $\alpha = 0$ implying that the entire fishing area comprises only exclusive economic zones and $\alpha = 1$ implying that the entire area comprises only the common property high seas. All results are tested in the entire interval in steps of $\Delta\alpha = 0.05$. Note that the carrying capacities, k_{EEZ} and k_{HS}, follow from the allocation parameter α and the total carrying capacity k_{tot} (see section 2.2, equation (2)). Finally, the impacts of the scope parameter $\gamma \in [0,1]$ as well as of the compatibility parameter $\lambda \in [0,1]$ are analysed in the entire range in steps of $\Delta = 0.2$.

Note finally that if not stated otherwise, all subsequent results hold for the entire parameter range outlined above and summarized in Table II.

3.4 Applications and Analytical Results

Table III provides an overview of applications related to the two most important parameters of our model: α, the portion of the high seas and d, the degree of diffusion. Clearly, the entries in Table III have to be interpreted in qualitative terms as exact data on these parameters is not available. For instance, species which predominantly occur in the high seas have been placed in cells 3, 6 and 9 with α close to 1 whereas species which are mainly found in EEZs are located in cells 1, 4 and 7. Straddling fish stocks would be typically in cells 4 and 5 and highly migratory fish stocks in cell 8 (see also footnote 2).

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16 Our mean values, $c = 0.5$ and $r = 0.5$, are commonly assumed in the literature (e.g. Hannesson 1997 and Tarui et al. 2008).

17 Results for $d = d_{max}$ differ less than 5 % from the results in the limit $d \to +\infty$, which can be calculated analytically. See subsection 3.4.

[Table III about here]

In terms of analytical results, consider first the standard scenario. If we let $\alpha = 1$, then this is the model with high seas only for which Pintassilgo and Lindroos (2008) have derived analytical solutions in the second stage. They also showed that no non-trivial coalition is stable for more than 2 players. Note that in our model diffusion does not matter for $\alpha = 1$ because diffusion is measured between and not within a zone. Hence, cells 3, 6 and 9 are identical for $\alpha = 1$ from an analytically point of view and are de facto the same in terms of applications for α close to 1.

By the same token, we can conjecture that if we let d go to infinity, then the value of α does not matter. Essentially, the allocation of property rights becomes irrelevant because very fast diffusion effectively links them to one zone. De facto we model the situation "only high seas" with $\alpha = 1$. This conjecture is confirmed by the results of our simulations for high values of d (see footnote 17). Hence, again, analytical results for cells 7, 8 and 9 follow from Pintassilgo and Lindroos (2008) for d going to infinity. Finally, if $\alpha = 0$ and $d = 0$, located in cell 1, there is no externality. Hence, second stage fishing efforts are socially optimal regardless of which coalition forms. Consequently, there is no gain from cooperation but also no incentive to free-ride and hence the grand coalition is stable.

Taken together, new interesting results can only be obtained in the interior parameter space where either α or d have to be positive and neither of these parameters takes on its maximum value. It is for this reason that simulations are needed even for the standard scenario but, as we explain below, also for the alternative scenarios.

Consider now the first alternative scenario related to the scope of measures. First note that if $\alpha = 1$, the scope of measure does not matter as there are no EEZs which need to be controlled by the RFMO. The same applies whenever $d = 0$, meaning that EEZs and high seas are not linked via migration. As argued above, if diffusion goes to infinity, we essentially have $\alpha = 1$, and hence at the limit there is again no difference between this alternative and the standard scenario.

Finally, consider the second alternative scenario related to the compatibility of measures. We note that for either $\alpha = 0$ or $\alpha = 1$, compatibility will not matter because this implies that there are only EEZs or only the high seas, respectively. Compatibility will also not matter if zones are not linked, i.e. $d = 0$.

Taken together, we can conclude that only in the interior of the parameter space, i.e. $d > 0$ and $\alpha < 1$, for which simulations are required, we can expect different results between the standard and the two alternative scenarios.

4. Results: Standard Scenario

In this section, we briefly summarise results obtained for the standard scenario as derived in Finus (2011) based on simulations and derived analytically in Pintassilgo and Lindroos (2008) and Pintassilgo et al. (2010) for $\alpha = 1$. In particular, we will focus on highlighting the underlying forces of coalition formation.

First, pick any (trivial or non-trivial) coalition, and consider the second stage. An increase in the price p, efficiency parameter q, and intrinsic growth rate r will increase individual and aggregate efforts and payoffs. The opposite is true for an increase in the cost parameter c. This is in line with basic economic intuition. Moreover, the larger the portion of the common property α and the larger the diffusion parameter d, the higher will be total equilibrium efforts but the lower will be total payoffs as long as the grand coalition has not formed (in which case the value of α and d does not matter). In other words, as long as the externality is not completely internalised, the externality is particularly pronounced in a strategic setting if α and d are large. Interestingly, if a two-player coalition has formed, the outsider's effort and payoff increase in α and d, i.e. the free-rider behaviour undermining the coalition effort to control fishing is particularly pronounced. Generally, moving from the all singleton coalition structure to a two-player coalition means that coalition members' efforts decrease and the outsider's effort increases, though total effort decreases. This illustrates that reaction functions are negatively sloped (and hence fishing efforts are strategic substitutes), though with a slope less than one in absolute terms. Moving finally to the grand coalition implies that coalition members' efforts as well as total efforts further decrease. Hence, a sequential increase of the coalition leads to a gradual decrease of the externality.

Moving now backwards to the first stage in which membership is decided, the following observations are important. Joining a coalition helps to internalise an externality. The success depends on the extent to which the outsider will countervail this effort by expanding his fishing effort. As pointed out above, such free-rider behaviour is particularly pronounced if α and d are large. The mirror image means that leaving a coalition (e.g. a two-player coalition or the grand coalition) is particularly attractive if α and d are large. It is exactly for this reason that in this model the grand coalition is not stable for any positive value of α and d and even a two-player coalition is only stable if both values are small. Specifically, whenever $\alpha \geq 0.02$ or $d \geq 0.32$ for the base values of the cost parameter ($c = 0.5$) and the growth parameter ($r = 0.5$), stability of a two-player coalition always fails. The boundary value for d increases in c and r. Higher production costs discourage fishing and a higher growth rate puts less pressure on the scarce resource. Hence, increasing both parameters to their maximum value 0.75 considered in the simulations, cooperation of a two-player coalitions now fails whenever $\alpha \geq 0.02$ and $d \geq 0.72$.

5. Results: Restricted Scope of Measures

In this section, we discuss the impact of a restricted scope of measures. In order to understand the driving forces, we look at each stage separately, and then draw overall conclusions. We proceed according to the sequence of backwards induction, starting with the second stage.

5.1 Second Stage of Coalition Formation

In the second stage, equilibrium fishing efforts, stocks, and payoffs depend on the scope parameter γ for every possible coalition structure different from the all singletons coalition structure.[18] Recall that the scope parameter γ measures the degree to which the RFMO can control fishing in the EEZs of its members. It does not matter in the cases 'only high seas' ($\alpha = 1$) and 'all zones are isolated' ($d = 0$); see Table III. In contrast, whenever $0 \leq \alpha < 1$ and $d > 0$ hold, the scope of measures matters. The only exception is the all-singletons coalition structure where the scope does not matter because no RFMO has formed in the first place.

Result 1: Restricted Scope of Measures and Equilibrium Efforts, Stocks and Payoffs

Assume $0 \leq \alpha < 1$ *and* $d > 0$ *and consider the two-player or grand coalition.*

a) *An increase in the scope parameter* γ *leads to lower total fishing efforts and higher total stocks and total payoffs where totals refer to the aggregation over all players and zones.*

b) *The impact of an increase of the scope parameter* γ *on total efforts, stocks and payoffs increases in the diffusion parameter* d.

Result 1a conforms to intuition regarding the grand coalition. In the absence of strategic interaction, any restriction of the scope of measures implies a departure from first best, which reduces the biological effectiveness of a cooperative agreement (i.e. higher fishing efforts and hence lower stocks), and decreases payoffs. Less obvious is that this also holds under the two-player coalition with strategic interaction between the coalition and the outsider. The reason is that the smaller the scope of measures (the smaller γ), the larger are coalitional fishing efforts which are only partially compensated by lower

18 In the following, we omit the term 'equilibrium' for notational convenience.

fishing efforts of the outsider because reaction functions have a slope less than 1 in absolute terms. Hence, conceding costal states sovereignty in intra-EEZ fishery management threatens the success of a given RFMO. In terms of aggregate payoffs, this is illustrated with an example in Table IV.

[Table IV about here]

Result 1b stresses the significance of diffusion. The negative impact of a restricted scope of measures, both in terms of the biological effectiveness and economic success of an RFMO, is more pronounced when stocks are highly mobile. Thus, the strong emphasis on a fully integrated fishery management in the case of highly migratory species, as expressed in the UNCLOS in 1982 and the UN Fish Stocks Agreement in 1995, is supported by our findings, at least as long as we abstract from the stability of agreements, related to the first stage of coalition formation, which we consider below.

5.2 First Stage of Coalition Formation

Now we investigate how the scope of measures affects the stability of coalitions. In order to appreciate the result, we may recall that for the standard scenario the grand coalition was only stable for $\alpha = 0$ and $d = 0$ and the two-player coalition was not stable whenever α or d was too large. Restricting the scope of measures may change this result.

Result 2: Restricted Scope of Measures and the Stability of Coalitions

The parameter spaces $\alpha \geq 0$ *and* $d \geq 0$ *for which the grand coalition and the two-player coalition are stable can be enlarged by reducing the scope of measure, i.e. by departing from the value* $\gamma = 1$.

Result 2 is encouraging: in contrast to the negative consequences of a reduced scope of measures on second stage outcomes (e.g. measured in terms of stocks and payoffs), it can have a positive impact on first stage outcomes by helping to stabilize RFMOs. This is illustrated with our example in Table IV. The largest stable coalition with the full scope of measures ($\gamma = 1$) is a two-player coalition. Reducing γ to at least $\gamma = 0.4$ allows stabilizing also the grand coalition.

The intuition behind Result 2 is that countries are more willing to join an RFMO if they can keep full or partial national sovereignty over intra-EEZ fishery management. This enables them to derive a larger exclusive benefit in their EEZs from the conservation measures implemented by the RFMO in the high seas. In other words, within their EEZs coalition members are partially allowed to free-ride on the cooperative efforts of the RFMO in which they participate. Hence, we conclude that a departure from first-best – being less ambitious – may buy larger stable membership in RFMOs. Technically, the difference between signatories' and non-signatories' fishing efforts decreases and hence the incentive to free-ride.

5.3 Overall Result

Second stage outcomes, Result 1, and first stage outcomes, Result 2, revealed two countervailing tendencies associated with a reduction in the scope of measures. Not surprisingly, combining both results only allows for a very general statement (Result 3), though the subsequent representative example and numbers are quite revealing.

Result 3: Restricted Scope of Measures and the Overall Success of RFMOs

Restricting the scope of measures, i.e. departing from the value $\gamma = 1$, can be welfare-improving.

For instance, consider again the example in Table IV. Without restriction of the scope of measures, $\gamma = 1$, the highest aggregate payoff of a stable coalition is generated by a two-player coalition (with a welfare level of 97.3%). For $\gamma = 1$, the grand coalition (which would generate the benchmark welfare level set to 100%) is not stable. Testing whether an improvement over this outcome is possible means to lower γ to a point which just allows stabilizing the grand coalition. In the example, this requires to lower γ to a value of 0.4. For $\gamma = 0.4$, the grand coalition generates an aggregate welfare level of 98.3% and therefore constitutes an improvement over the two-player coalition. Obviously, lowering γ further makes no sense as this increases the negative second stage effect which cannot be compensated by a positive first stage effect as the maximum membership has already been obtained in this example.

Other examples would confirm this result which implies that global welfare is a step function. Reducing the scope of measures γ gradually reduces global welfare until a point may be reached where global welfare jumps up to a higher level due to larger stable membership.

Hence, given the restriction that RFMOs have to be self-enforcing, in a strategic setting, restricting the scope of measures can be welfare improving. Clearly, there are cases where this is not possible, e.g. "unfavourable" parameter values generating large externalities and free-rider incentives for non-signatories, like large values of α and d, where even with values of γ below 1 no RFMO is stable. If we rule out these parameter values and consider $\alpha \leq 0.2$ and $d \leq 0.32$ (but consider the full range of all other parameters as stated in Table II), we find that in 15% of the cases a restricted scope leads to better outcomes than a full scope; if an improvement is possible, the "optimal scope" leads to the grand coalition in 92 % of the cases and to the two-player coalition in 8% of the cases. Hence, we can conclude that a departure from first best may well be rational, though the socially optimal welfare level can never be obtained which necessarily requires to set $\gamma = 1$ and the inclusion of all players in an RFMO.

6. Results: Restricted Compatibility of Measures

We now turn to the second alternative scenario, considering a restricted compatibility of measures. Again, we follow the sequence of backward induction.

6.1 Second Stage of Coalition Formation

First, recall that for the two extreme assumptions $\alpha = 0$ (only EEZs and no high seas) and for $\alpha = 1$ (only high seas) the compatibility of measures is irrelevant for the second stage, irrespective of the coalition structure which has formed in the first stage. The same holds if all zones are isolated because there is no migration $(d = 0)$. In contrast, whenever there are two distinct legal regimes $(0 < \alpha < 1)$ and the stocks in the different zones are linked to each other via diffusion ($d > 0$; though d does not go to infinity) the compatibility of measures matters, as described in Result 4.

Result 4: Restricted Compatibility of Measures and Equilibrium Efforts, Stocks and Payoffs

Assume $0 < \alpha < 1$ *and* $d > 0$ *and consider any possible coalition structure.*

a) *An increase in the compatibility parameter* λ *leads to lower total fishing efforts and higher total stocks and total payoffs.*

b) *The impact of an increase of the compatibility parameter* λ *on total efforts, stocks and payoffs increases in the diffusion parameter* d *.*

Result 4a stresses that neglecting the need for compatibility leads to a rise in aggregate fishing efforts, a decline in stocks and thereby decreasing aggregate payoffs. An example in Table V illustrates this point for aggregate payoffs.

[Table V about here]

Result 4b points to the fact that the compatibility of measures is more important in the case of highly migratory stocks (high value of d) where fishing in one zone creates a stronger externality on stocks in neighbouring zones than in the case of straddling stocks (low value of d).

6.2 First Stage of Coalition Formation

Recall that the all-singletons coalition structure is stable by definition for all parameter values and that the grand coalition is only stable when cooperation does not matter ($\alpha = 0$ and $d = 0$) under the standard scenario corresponding to the full compatibility of measures, $\lambda = 1$. Hence, Result 5 focuses on the more interesting cases when either $\alpha > 0$ or $d > 0$.

Result 5: The Compatibility of Measures and the Stability of Coalitions

The parameter space ($\alpha \geq 0$ and $d \geq 0$) *for which the two-player coalition is stable is larger under a limited compatibility of measures, i.e. for* $\lambda < 1$. *The grand coalition is never stable*

Result 5 is very similar to Result 3: a departure from the first-best management strategy can help to stabilize larger coalitions. The representative example in Table V illustrates this point. If λ is lowered to $\lambda = 0.2$ the two-player coalition will be stable. More generally, a restricted compatibility of measures means a less ambitious fishery policy to control overfishing and hence the free-rider incentives are also lower, leading to larger coalitions compared to the standard scenario.

6.3 Overall Result

We now pull the results from the first and second stage together.

Result 6: The Compatibility of Measures and the Overall Success of Coalitions

A limited compatibility of measures $(\lambda < 1)$ *may increase global welfare.*

In view of the numerous international fisheries conventions that emphasize the importance of the compatibility of measures, Result 6 suggests that conclusions may be different if we explicitly account for strategic aspects of free-riding. Again, global welfare is a non-continuous step function of the parameter λ as illustrated for the example in Table V. Apparently, a high value of λ leads to higher aggregated payoffs but may not allow to stabilize a non-trivial RFMO. The highest total payoff (86.4%), generated by a stable coalition of two players, occurs for $\lambda = 0.2$ in this example which dominates the highest possible payoff of the all-singletons coalition structure (85%) which occurs for $\lambda = 1$. Hence, a restricted compatibility of measures can be welfare-improving. Again, we test for the entire parameter range in Table I, except that we assume $\alpha \leq 0.2$ and $d \leq 0.32$, and find that in 49% of the cases a restricted compatibility (i.e. $\lambda < 1$) can improve upon an unrestricted compatibility, i.e. the standard scenario.[19]

7. Excluding Non-Members from Fishing

There have been continuous efforts to make RFMO membership (or at least compliance with RMFO regulation) mandatory. That is, RFMOs can exclude non-members from fishing in the high seas areas under their jurisdiction, as for instance suggested by the *International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing* (FAO 2001). In fact, Art. 8(4) of the 1995 UN Fish Stocks Agreement states that "*Only those States which are [RFMO] members [...] shall have access to the [respective] fishery resources*." However, this provision and similar attempts to enforce RFMO regulations have always been highly controversial as they are obviously inconsistent with the *freedom of the high seas* set forth in Art. 87, UNCLOS 1982. Nonetheless, we will briefly discuss how our results changed if exclusion of non-members would be possible. For this, we assume the standard scenario in the second stage.

First, note that equilibrium fishing efforts, stocks and payoffs remain unaffected in the grand coalition (as there are no outsiders to be excluded), as well as if no coalition has

[19] We also investigated the assumption that signatories choose fully compatible measures but only non-signatories a restricted compatibility. In terms of stability of coalitions, this turns out to be an unsuccessful strategy. The reason is simple. Compared to the standard scenario, fishing efforts of non-signatories increase, undermining the efforts of signatories to control fishing of the RFMO even more.

formed at all (as we assume that an RFMO needs at least two members to be able to enforce its regulation in the high seas). Thus, we only have to consider a two-player coalition where we have to set $E_{HS,j} = 0$, $j \notin S$ when solving the first order conditions resulting from condition (4) and (5). Second, note that excluding a non-member from fishing in the high seas, lowers the free-rider's payoff and at the same time increases the payoff of members. Consequently, leaving a coalition becomes less attractive. Moreover, the aggregate payoff of a two-player coalition is larger with than without exclusion.

Result 7: Coalition Stability with Exclusion of Non-Members

If exclusion of non-members from fishing in the high seas is possible, then

a) the parameter space for which the two-player coalition is stable is significantly larger than without exclusion;

b) the grand coalition is stable for a wide range of parameter values;

c) the parameter space for which a two-player and the grand coalition are stable increases with α.

Clearly, the possibility to evict non-cooperating fishing nations from the high seas is beneficial for the stability of cooperation. Not only stability of a two-player is much more likely but also the grand coalition can be stable, and this is true for a large set of parameters. Interestingly, the role of the allocation parameter α is reversed. Without exclusion, already a two-player coalition fails to be stable whenever α is sufficiently large, and the grand coalition is never stable (except for $\alpha = 0$ and $d = 0$) whereas with exclusion, even the grand coalition turns out to be stable whenever α is sufficiently large. This is not surprising because if exclusion is possible, the larger the common pool area (high values of α) is the larger the exclusive benefits to coalition members and the lower the free-riding benefits to outsiders are. Thus, if the recurrent attempts to make RFMO membership mandatory are successful, privatizing large portions of the high seas would be counterproductive. Obviously, this scenario assumes a substantial amount of enforcement power of RFMOs, most likely an overly optimistic view regarding future enforcement of international law.

8. Conclusion

The United Nations Convention on the Law of the Sea (UNCLOS) in 1982 emphasized the sovereignty of coastal states' fisheries management within the substantially enlarged areas under national jurisdiction and, at the same time, called for cooperation of fishing nations in the high seas. However, many commercially valuable species are found both within and beyond EEZ boundaries. This raises the question how a consistent management of fish stocks can be ensured. The UN Fish Stocks Agreement in 1995 and many current RFMOs address this issue by calling for the consistency of management measures implemented by coastal states and RFMO authorities. Ideally, coastal states should hand over their sovereignty to the RFMO authorities. However, as argued in the introduction, the current practice provides many examples of inconsistent management and the issue has remained largely unresolved. While several authors have discussed how full compatibility and scope of management could be implemented (e.g. Oude Elferink 2001, Molenaar 2005), it has been little understood so far how a departure from a first-best management strategy affects the overall success of RFMOs if stability is a binding constraint.

To this end, we have developed an integrated model for internationally shared fish resources that explicitly captures the spatial dimension and accounts for the migratory nature of many commercially important fish species. Our model accounts for the fact that coastal states have been granted exclusive sovereign rights over their exclusive economic zones under the UNCLOS in 1982, but the area outside their territory, the high seas, can be exploited by all fishing nations.

In a two-stage coalitional game where countries first decide upon their membership in an RFMO and then choose their fishing efforts, we have approached the issue along two avenues. The first scenario considered a restricted *scope of measures*, allowing for the possibility that the RFMO cannot fully control fishing in the EEZs of its members. This means that RFMO members do not fully concede their sovereignty to the governing body of the RFMO. The second scenario analysed a restricted *compatibility of measures*. We gradually relaxed the assumption that players fully account for the negative impact of fishing in their EEZ on the payoffs they receive from the high seas and vice versa. Both scenarios implied a departure from first-best and capture the notion of various degrees of second-best management of fishery resources.

Interestingly, the qualitative results of both alternative second-best scenarios have been quite similar and hence our conclusions appear robust. For any given RFMO membership structure, a departure from first best has a negative impact, either measured in biological terms (fish stocks) or economic terms (payoffs). However, such a departure can also have a positive impact on membership in that it can “buy” additional membership. Second-best designs of treaties means de facto to put less pressure on RFMO members to reduce their fishing efforts in order to preserve fish stocks. Those less ambitious objectives reduce the free-rider incentive, helping to establish larger stable participation in RFMOs. It has been shown that – at least in theory - an “optimal departure from first best” can be determined for this trade-off between the level of ambition and participation, which maximizes global economic rents of stable RFMOs.

In the light of our result, many current suboptimal forms of fishery management may be less harmful than commonly perceived. Clearly, this does not question the normative benchmark of first-best fishery management, but only points to the fact that as long as free-riding cannot be effectively controlled by a global authority, a bird in hand may be more valuable than two in the bushes. This also suggests that in developing treaties, the main focus should be first on encouraging participation and only later on deepening treaties in terms of their objectives.

Finally, we briefly considered the possibility that RFMO members can prevent non-members from fishing in the high seas. Though we argued that this may be an overly optimistic assumption regarding the enforcement power of RFMOs and most likely not in line with international law, it has become clear that this would substantially enhance the success of RFMOs.

For future research several topics come to mind. Our assumption about the migration pattern covers a large group of fish species, but there remain some species which may be better captured by different assumptions, e.g. linear migration patterns. It would be interesting to find out whether our qualitative conclusions would carry over to such alternative assumptions. Furthermore, the prospects of marine protected areas (i.e. nature reserve with no or restricted fishing, like analysed in Punt et al. 2013) in the light of migration could be evaluated. Also the impact of asymmetric migration patterns as well as other forms of asymmetries across fishing nations on the success of coalition formation along the lines in Pintassilgo et al. (2010) could be interesting. Finally, a more sophisticated bargaining protocol as for instance suggested in Caparrós et al. (2004) could be employed.

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Table I: Functional Specification of Model

1)	Growth Functions	$G_i\left(X_i\right)=r_iX_i\left(1-\dfrac{X_i}{k_{EEZ}}\right),\ i=1,...,N\ ;\ G_{HS}\left(X_{HS}\right)=r_{HS}X_{HS}\left(1-\dfrac{X_{HS}}{k_{HS}}\right)$
2)	Harvest Functions	$H_{EEZ,i}\left(X_i\right)=q_iE_{EEZ,i}\dfrac{X_i}{k_{EEZ}},\ i=1,...,N\ ;\ H_{HS}\left(X_{HS}\right)=\sum_{i=1}^{N}q_iE_{HS,i}\dfrac{X_{HS}}{k_{HS}}$
3)	Migration Process	Entries of the dispersal matrix D: $d_{ij}=\begin{cases} d\sqrt{k_i/k_j} & \text{if i adjacent to j} \\ 0 & \text{otherwise} \end{cases}\quad \forall i\neq j$ $d_{ii}=-\sum_{j\neq i}d_{ji}\quad \forall i$
4)	Cost Functions	$C_i(E_{EEZ,i})=c_iE_{EEZ,i}\ ,\ i=1,...,N\ ;\ C_i(E_{HS,i})=c_iE_{HS,i}\ ,\ i=1,...,N$

r_i, r_{HS} = intrinsic growth rate in region i and HS, respect.; X_i, X_{HS} = stock in EEZ_i and HS, respect.; k_{EEZ}, k_{HS} = carrying capacity in EEZ and HS, respect.; q_i = efficiency parameter of country i; $E_{EEZ,i}$, $E_{HS,i}$ = efforts in EEZ_i and HS, respect.; d_{ij} = diffusion parameter between region i and j; c_i = cost parameter of country i .

Table II: Parameter Values in Simulation Runs*

Simulation Runs	$c=c_i=c_j$	$r=r_i=r_j$	d	α	γ	λ
Scope	0.25-0.75	0.25-0.75	0-1.28	0-1.0	0-1.0	-
Compatibility	0.25-0.75	0.25-0.75	0-1.28	0-1.0	-	0-1.0

* $p=1$, $q=1$ and $k_{tot}=4$ are assumed throughout.

Table III: Analysis and Classification of Commercially Important Fishery Resources

	α close to 0, stocks are located predominantly within EEZs	0<<α<<1, stocks inhabit EEZs and the high seas	α close to 1, stocks are located predominantly in the high seas
d close to 0, weak migration	**Description:** stationary species that are located mainly within EEZs. **Examples:** largehead hairtail, European pilchard, lobster, oyster, flounder, plaice, Akiami paste shrimp. **Standard Scenario:** grand coalition is stable if $\alpha = 0$ & $d = 0$; 2-player coalition is stable if α and d are not too large. **Alternative Scenarios:** minor impact because d close to 0. **Remark:** analytical results are possible for $\alpha = 0$ & $d = 0$.** **1**	**Description:** stationary species that are located both in EEZs and high seas. **Examples:** orange roughy (some populations). **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** minor impact because d close to 0. **Remark:** simulations required. **2**	**Description:** stationary species that are located mainly in high seas. **Examples:** orange roughy (some populations). **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** minor impact because d close to 0 and/or α close to 1. **Remark:** analytical results are possible if $\alpha = 1$ because then d does no matter. * **3**
d intermediate, moderate migration	**Description:** migratory species that migrate mainly between EEZs. **Examples:** rock sole and arrowtooth flounder in Eastern Bering Sea, chub mackerel, haddock . **Standard Scenario:** 2-player coalition is stable if α and d are not too large. **Alternative Scenarios:** scope of measures matters; compatibility of measures has minor impact because α close 0. **Remark:** simulations required. **4**	**Description:** migratory species that migrate through EEZs and high seas. **Examples:** North-east Atlantic cod, North-west Atlantic cod (before collapse), Atlantic herring, Alaskan Pollock. **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** scope and compatibility of measures matter. **Remark:** simulations required. **5**	**Description:** migratory species that migrate mainly within high seas. **Examples:** hoki. **Standard Scenario:** no non-trivial is coalition stable. **Alternative Scenarios:** minor impact because α close to 1. **Remark:** analytical results are possible if $\alpha = 1$ because then d does no matter. * **6**
d large, strong migration	**Description:** highly migratory species that migrate mainly between EEZs. **Examples:** salmon. **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** scope of measures matters; compatibility of measures minor impact because α close 0. **Remark:** analytical results possible if $d \to +\infty$.* **7**	**Description:** highly migratory species that occur in EEZs and high seas. **Examples:** skipjack tuna, bigeye tuna, yellowfin tuna, bluefin tuna, albacore tuna and marlin. **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** scope and compatibility of measures matter. **Remark:** analytical results possible if $d \to +\infty$.* **8**	**Description:** migratory species that occur mainly in high seas. **Examples:** mink whale. **Standard Scenario:** no non-trivial coalition is stable. **Alternative Scenarios:** minor impact because α close to 1. **Remark:** analytical results possible if $\alpha = 1$ because then d does no matter * **9**

Legend: Examples collected from FAO (2013), Sea Around Us Project online, Froese and Pauly (2014) and ICES (2013). With respect to footnote 2, cell 1,4 and 7 relate to transboundary stocks, cell 5 to straddling stocks, cell 8 to highly migratory stocks and cells 3, 6 and 9 to discrete stocks. The table classifies species according to the strength of migration, irrespective of the migration pattern. Density-dependent migration is presumed for instance for herring, haddock and Atlantic cod, was discussed for some Alaskan pollock and various tuna species, but does not apply to salmon for instance. Standard Scenario refers to results from Finus et al. (2011). Remarks: *: analytical results in Pintassilgo and Lindroos (2008) for $k_{tot}=4$ and $N=3$. **: analytical results obvious, i.e. social optimum for $\alpha=0$, $k_{tot}=4$ and $N=3$ in Pintassilgo and Lindroos (2008).

Table IV: Scope of Measures: Total Payoffs*

Coalition Structure	$\gamma = 1$	$\gamma = 0.8$	$\gamma = 0.6$	$\gamma = 0.4$	$\gamma = 0.2$	$\gamma = 0$
No Cooperation	**94.2**	**94.2**	**94.2**	**94.2**	**94.2**	**94.2**
Two-Player Coalition	**97.3**	**96.9**	**96.5**	95.9	95.1	**94.2**
Grand Coalition	100	99.8	99.3	**98.3**	**96.7**	**94.2**

* Total payoffs (expressed as a percentage of the total payoff in the social optimum) for various coalition structures and values of the scope parameter γ. Total payoffs of stable coalition structures are in bold. The following parameter values are assumed: $d = 0.16$, $c = 0.5$, $r = 0.5$, $p = 1$, $q = 1$ and $k_{tot} = 4$ as well as $\alpha = 0$.

Table V: Compatibility of Measures: Total Payoffs*

Coalition Structure	$\lambda = 1$	$\lambda = 0.8$	$\lambda = 0.6$	$\lambda = 0.4$	$\lambda = 0.2$	$\lambda = 0$
No cooperation	**85.0**	**83.3**	**81.5**	**79.5**	**77.4**	**75.1**
Two-Player Coalition	93.3	91.9	90.2	88.4	**86.4**	**84.1**
Grand Coalition	100	99.9	99.5	98.9	97.9	96.6

* Total payoffs (expressed as a percentage of the total payoff in the social optimum) for various coalition structures and values of the compatibility parameter λ. Total payoffs for stable coalition structures are in bold. The following parameter values are assumed: $d = 0.16$, $c = 0.5$, $r = 0.5$, $p = 1$, $q = 1$ and $k_{tot} = 4$ as well as $\alpha = 0.25$.