THE INCENTIVE STRUCTURE OF IMPURE PUBLIC GOOD PROVISION –

THE CASE OF INTERNATIONAL FISHERIES

by

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Abstract

We argue that international fisheries are a prime example to study the impact of multiple characteristics, on the incentive structure of non-cooperative and cooperative impure public good provision. The degree of socially constructed excludability is captured by the distinction between the internationally (publically) accessible domain of high seas and the state-owned (privately owned) exclusive economic zones, as defined by international law; the degree of technical excludability is related to the pattern of fish migration between various zones and the degree of rivalry is reflected by the growth rate of the resource. Hence, our model is also capable of analyzing the benefit-cost duality between public goods and common pool resources.

JEL References: C72, F64, H87, Q22

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1 Introduction

There are many cases of international and global public goods for which the decision in one country has consequences for other countries and which are not internalized via markets. Reducing global warming and the thinning of the ozone layer are examples in case. As Sandler (1998), p. 221, points out: “Technology continues to draw the nations of the world closer together and, in doing so, has created novel forms of public goods and bads that have diminished somewhat the relevancy of economic decisions at the nation-state level.” The stabilization of financial markets, the fighting of contagious diseases and the efforts of non-proliferation of weapons of mass destruction have gained importance through globalization and the advancement of technologies.

A central aspect in the theory of public goods is to understand the incentive structure that typically leads to the underprovision of public goods as well as the possibilities of rectifying this. The incentive structure can be broadly related to the *properties of public goods* which are usually associated with two distinguishing features: non-excludability and non-rivalry, which can be traced back to the seminal work of Samuelson (1954) and Musgrave (1959). By varying the degree of excludability and rivalry, various mixed forms of impure public goods emerge as illustrated in Table 1 (e.g. Cornes and Sandler 1984, 1994 and Kaul and Mendoza 2003).

In terms of *excludability*, the expectation is that the higher the degree of excludability, the closer are non-cooperative equilibrium and optimum, but also the smaller are the gains from cooperation.[1] Kaul and Mendoza (2003) emphasize that the perception of what is public and what is private has changed significantly over time. They distinguish between the intrinsic properties of a good, to which for instance the so-called *technical excludability* belongs, and the properties assigned by society to them, to which they refer to as so-called *socially constructed excludability*. Whereas the degree of technical excludability can be regarded as given, at least in the short and mid-term (e.g. through physical exclusion devices, such as barbed wire fences and electronic sensing devices in the fight against international terrorism),

[1] The importance of private benefits has been emphasized for instance by Cornes and Sandler (1984), p. 595: "... the jointly produced private output can serve a privatising role, not unlike the establishment of property rights”; or by Sandler and Sargent (1995), p. 153: “private benefits act to raise the gains from unilateral cooperation [...] this serves to foster cooperation.”

socially constructed excludability is determined by the establishment and enforcement of property rights.

In terms of *rivalry*, the expectations appear to be less clear-cut. On the one hand, Sandler and Arce (2003) convincingly show the benefit-cost duality of pure public goods and common pool resources. In the public good game, the costs are private and the benefits from provision are public. In the commons game, the benefits are private and the costs from exploitation are public. On the other hand, despite their formal proof of equivalence, the authors conclude informally that there is a difference: in politics it would be easier to establish joint action in public good games than joint inaction (giving up rights) in commons games.

[Table 1 about here]

To the best of our knowledge, there is no formal model capturing the following three aspects simultaneously: 1) all the above-mentioned properties with varying degrees (i.e. different degrees of socially constructed and technical excludability as well as rivalry), 2) systematic analysis of their effect on the incentives of public good provision, and 3) test for the possibility to establish full or partial cooperation in a non-cooperative model of coalition formation.[2]

In terms of the first aspect, we view international fisheries as one of the few and particularly interesting examples where all properties are simultaneously present.[3] The degree of socially constructed and technical excludability can be parameterized along the entire horizontal

[2] It appears that a more comprehensive (though without coalition formation) and systematic analysis is available on the relation between the aggregation technology (e.g. weakest-link, weaker link, best-shot and better shot technology) and the incentive of public good provision. We do not pursue this interesting aspect here; see for instance (e.g. Arce 2001, Arce and Sandler 2001, Cornes and Hartley 2007, Sandler 1998 and Sandler and Sargent 1995).

[3] The sharing of water resources has similar features. Socially constructed excludability can be established through property rights and technical excludability may vary through the diversion of rivers and the erection of dams. However, many other examples feature only some properties. For instance, the acid rain game allows capturing various degrees of technical excludability though the emission transportation matrix (e.g. Mäler 1994 and Sandler 1998), but since national boundaries are given, the degree of socially constructed excludability is not an issue. The same applies to the classical example of a pure public good game, climate change mitigation, even if we recognize the privatizing effects of ancillary or co-benefits of improved local air quality from climate mitigation as analyzed for instance in Markandya and Rübbelke (2004). In the case of the exploration of the natural resources in the Antarctic (like, e.g. oil, gas and minerals), after property rights were properly defined and enforced, excludability would be perfect as technical excludability can be regarded as perfect. In terms of rivalry all examples are only located at one extreme of the spectrum: acid rain and climate change exhibit no rivalry at all whereas for non-renewable resources rivalry is perfect.

spectrum in Table 1. (For details see sections 3 and 4.) In our model, parameter α measures the degree of socially constructed excludability as this is the portion of the total fishing ground which is publicly accessible by all fishing nations (common property), the so-called high seas, and $1-\alpha$ is the portion of the total fishing ground which is privately own by coastal states, the so-called Exclusive Economic Zones (EEZs), as established by the UN Convention on the Law of the Sea in 1982.[4] The parameter d measures the degree of technical non-excludability and is related to the pattern and intensity of the migration of fish stocks between different zones. Also the degree of rivalry can be parameterized along the entire vertical spectrum in Table 1 through the growth rate of the fish stock (parameter r in our model; see sections 3 and 4 for details). This allows us to study the duality of public goods versus commons in a systematic way.

In terms of the second aspect, we measure the level of underprovision of the impure public good (i.e. "preservation of fish stocks") as the difference between fully cooperative, partially cooperative and non-cooperative equilibrium, physically in terms of stock levels and monetarily in terms of payoffs. Differences are related to the properties of the public good and important economic and biological parameters that determine the production process.

In terms of the third aspect, in the tradition of the literature on international environmental agreements (IEAs)[5] and the literature on international fishery agreements (IFAs)[6], we study the formation of self-enforcing agreements as a means to mitigate free-riding with a non-cooperative coalition model.[7] However, the IEA-literature has almost exclusively restricted

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4 In terms of terminology, in our setting "privately owned" and "privatization" means the allocation of property rights to states – the sole actors or players in our international fishery game. In the fishery literature, mainly with a national or regional focus, these terms are sometimes also used for the allocation of fishing quotas to fishermen. We abstract from these national details. See section 4.4 for the qualification of our assumptions.

5 The literature on IEAs goes back to Barrett (1994) and Carraro and Siniscalco (1993) and has grown immensely in recent years. For surveys see for instance Barrett (2003) and Finus (2003).

6 Stability of fishery agreements has been modelled as cooperative (e.g. Kennedy 2003 and Lindroos 2004) or non-cooperative coalition games (e.g. Kwon 2006, Pintassilgo et al. 2010 and Pintassilgo and Lindroos 2008), but also as a dynamic fishery game with enforcement through punishment (e.g. Hannesson 1997 and Tarui et al. 2008).

7 Possible options of mitigating free-riding discussed in the literature on public goods are for instance correlated equilibria in chicken games (e.g. Arce and Sandler 2001), evolutionary stable strategies through "leading by example" (e.g. Arce 2001), non-Nash behaviour in conjectural variation equilibria (e.g. Cornes and Sandler 1983). To the best of our knowledge, coalitions have only been considered from a cooperative game theory perspective (e.g. Arce and Sandler

attention to a global emission game[8] (i.e. pure public bad) and the IFA-literature considered a renewable common resource with only one jurisdiction.[9] In contrast, we allow for the possibility that for some parts of the ocean property rights are established through the declaration of EEZs. Among EEZs and the high seas there are links through the migration of fish. This is modelled using the classical Gordon-Schaefer model (Gordon 1954) which is extended to account for migration between different fishing grounds as considered for instance in Sanchirico and Wilen (1999, 2005).

The paper proceeds as follows. In section 2, we provide a brief background on the historical development of the management of international fisheries and the establishment of cooperative agreements. In section 3, we introduce the bioeconomic model including the two-stage coalition formation model. Section 4 describes the model specifications and our solving procedure. According to the sequence of backward induction, we first discuss results of the second stage (section 5), then of the first stage (section 6) and finally pull results of both stages together in section 7, which sums up our main findings, discusses their policy implications and briefly mentions the outcome under a different institutional scenario. We would like to point out at the outset that although our model relates to international fisheries, our aim is to remain as general as possible with reference to the literature on public goods and hence we abstract from technical details investigated in some literature on fisheries.

2 Historical Background on International Fishery Management

The Food and Agriculture Organization of the United Nations (FAO) estimates that harvests from internationally shared fish stocks[10] account for as much as one third of global marine

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2003 and Sandler 1999); but there the focus is not on enforcement but on sharing the gains from cooperation in the grand coalition.

8 Exceptions are for instance Mäler (1994) and Finus and Tjøtta (2003) in the context of a repeated acid rain game, though they only focus on the stability of the grand coalition and do not exploit the relation between transportation coefficients (i.e. measuring the degree of technical excludability) and the success of cooperation.

9 Already Crutchfield (1964), p. 216, based his call for international cooperation on the observation that migration of fish poses a natural limit to the privatization of fishery resources: "[...] the fish themselves seem indisposed to accept such [privatizing] solutions."

10 According to FAO's classification there are four categories of shared: transboundary stocks (resources that cross the EEZs of two or more coastal states); highly migratory stocks (found both within the EEZs and the adjacent high seas and highly migratory in nature); straddling stocks (also cover both EEZs and the high seas but are more stationary); discrete high seas stocks (found exclusively in the high seas).

capture fishery harvests (FAO 2010 and Munro et al. 2004). These stocks are estimated to be particularly vulnerable and are reported to be heavily overexploited or even depleted in McWhinnie (2009).

For a long time, concern mainly focused on the preservation of coastal fishing grounds. Some governments started to declare unilaterally EEZs, thus evicting all foreign fleets from what they claimed to be their private property. The 1982 UN Convention on the Law of the Sea (UNCLOS) harmonized and legalized the various unilateral declarations in assigning the right to coastal states to establish EEZs, comprising 200 nautical miles. After some initial success, it became clear that further action was required as the significance of high seas fisheries had been underestimated. In particular, technological progress, such as the introduction of fish carriers and vessels with on board fish processing equipment, had made the resources of the high seas more accessible. Increasing awareness of overfishing led to the 1995 UN Fish Stocks Agreement. Under this agreement, shared fish stocks are to be managed, on a region by region basis, by Regional Fisheries Management Organizations (RFMOs). There are currently 20 RFMOs in force as for example the Northwest Atlantic Fisheries Organization (NAFO) and the North East Atlantic Fisheries Commission (NEAFC).[11] As participation in RFMOs is voluntary, cooperative efforts have frequently been undermined by fishing activities of non-members. While there is 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. However, also monitoring and enforcement among RFMO members have not been a trivial task.[12]

11 For an overview see for instance Munro et al. (2004) and FAO online (2012).

12 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. NEAIC 2006, ICCAT 2009 and IOTC 2009) a rather pessimistic picture emerges.

3 Model

3.1 Preliminaries

Our model aims at capturing the impact of different degrees of socially constructed and technical excludability as well as the degree of rivalry on the exploitation of a common property resource. This is done in a systematic, though stylized way for analytical tractability.

The dynamics of the fish stock are captured by our biological model which is developed in section 3.2. Due to the complexity of coalition formation and the consideration of migration of fish stocks across different fishing zones, we stick to a steady-state analysis.[13] The economic model is laid out in section 3.3. It captures the strategic behavior among nations under various assumptions about the degree of cooperation; it also includes the definition of stable cooperative arrangements.

3.2 Biological Dimension

The biological model is based on the classical Gordon-Schaefer model (Gordon 1954 and Schaefer 1954) which has been frequently used to analyze the steady-state of an exploited renewable (fish) resource. This model is extended to account for different fishing zones and the migration of fish stocks across zones.

We assume that a given number of players N exploit a shared natural resource of size k.[14] In the context of biological populations, k is called the carrying capacity of the biological system, which we interpret as the geographical size of the system as in Pezzey et al. (2000). In our context, the resource is the fish stock and the biological system is the ocean. Parts of the system may have been privatized through the establishment of exclusive economic zones. Hence, there are two types of geographical zones: the high seas, abbreviated HS, the

13 It is well-known that some specific results obtained from a steady-state analysis differ from those derived from a fully-fledged dynamic optimization programme (e.g. Perman et al. 2011). However, at our level of aggregation, and as long as coalition formation is not analyzed as a dynamic process over time, it should be expected that the main conclusions derived from our simpler analysis should remain valid in the fully dynamic analysis, as this is evident for instance by comparing the single zone coalition models in Pintassilgo and Lindroos (2008) and Kwon (2006).

14 Hence, in our setting, non-cooperative behaviour is not identical to what is called open access in the fishery literature. That is, rents are lower in the non-cooperative than in the cooperative equilibrium, but rents will not completely dissipate through entry.

common property where all nations can fish (Art. 87, UNCLOS 1982), and the exclusive economic zones, abbreviated EEZ_i, the private properties with exclusive fishing rights of coastal state i (Art. 56, UNCLOS 1982).

Denoting the entire size of the system by k_{tot} and the share of the resource for which no private property rights have been established by α, we define:

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

Henceforth, we call $\alpha \in [0,1]$ the allocation parameter for short, which measures the degree of socially constructed excludability in our model, with $\alpha = 0$ implying perfect socially constructed excludability and $\alpha = 1$ perfect non-excludability (see Table 1). In our context, players are sovereign countries engaging in fishing, i.e. coastal states, with exclusive access to their own EEZ and a shared access to the high seas. We abstract from the fact that EEZs could be of different size and that so-called distant water fishing nations without EEZ engage in fishing.

The steady-state condition is given by

$$\frac{d\boldsymbol{X}}{dt} = \boldsymbol{G}(\boldsymbol{X}) - \boldsymbol{H}(\boldsymbol{X},\boldsymbol{E}) + D\boldsymbol{X} = 0 \,, \tag{2}$$

with $\boldsymbol{X} = (X_1,...,X_N,X_{HS})$ the vector of fish stocks in the various zones[15], the vector of efforts, $\boldsymbol{E} = (E_{EEZ,1},...,E_{EEZ,N},E_{HS,1},...,E_{HS,N})$ which is a physical measure of input, e.g. time spent fishing, t denotes time, $\boldsymbol{G}(\boldsymbol{X})$ the vector of growth functions, $\boldsymbol{H}(\boldsymbol{X},\boldsymbol{E})$ the vector of harvest levels and the term $D\boldsymbol{X}$ accounts for migration of fish stocks across zones. Hence, equation (2) states that in the steady state, growth and harvest are balanced, accounting additionally for incoming or outgoing stock flows through migration, such that the stock in

15 We talk about different stocks in different zones, but one could also talk about different shares of the total stock. In any case, if we talk about the total stock, we mean the sum of the components of the vector $\boldsymbol{X}$. The total stock as well as its allocation is a result of equilibrium effort levels as described in section 3.3 and the exogenous parameters of the model, like for instance the allocation, diffusion and cost parameters.

each zone remains constant in time. Clearly, the higher growth, the more can be harvested in equilibrium and hence the lower is the degree of rivalry.

The components of $\boldsymbol{G} = (G_1,...,G_N,G_{HS})$ describe intrinsic growth in each zone, assuming that growth requires an initial population, $G_i\left(X_i = 0\right) = 0$ and $G_{HS}\left(X_{HS} = 0\right) = 0$, is positive as long as the carrying capacity has not been reached, $G_i\left(0 < X_i < k_{EEZ}\right) > 0$ and $G_{HS}\left(0 < X_{HS} < k_{HS}\right) > 0$ and stops at the carrying capacity, $G_i\left(X_i = k_{EEZ}\right) = 0$ and $G_{HS}\left(X_{HS} = k_{HS}\right) = 0$. The components of $\boldsymbol{H} = \left(H_{EEZ,1},...,H_{EEZ,N},H_{HS}\right)$ are the harvest levels in each zone which depend both on the vector of stocks, $\boldsymbol{X}$, and the vector of efforts, $\boldsymbol{E}$. Due to the migratory behavior of fish stocks, harvest from each zone generally depends on all fishing efforts. Finally, the dispersal or diffusion matrix $D = \left(d_{ij}\right)$, which is similar to the transportation matrix known from transboundary pollution, contains all information needed to describe the dispersal process; it is not only important whether zone i and zone j are connected via diffusion ($d_{ij} \neq 0$ and/or $d_{ji} \neq 0$) but also the strength of interaction, i.e. the absolute value of d_{ij} and d_{ji}.[16]

From a conceptual point of view, migration determines the degree of technical non-excludability. As it is virtually impossible to erect fences in the ocean to separate fish stocks, it is technically not feasible for a country to exclude other fishing nations entirely from benefiting from its fishery resources. Thus, there can be some degree of non-excludability, stemming from migration, even if socially constructed excludability is perfect, i.e. all property rights have been allocated to states, $\alpha = 0$, and these rights are perfectly enforceable through the declaration of EEZs (i.e. we rule out illegal fishing in EEZs).

3.3 Economic Dimension

Each player receives an economic rent or as we call it payoff Π_i that is obtained from the harvest extracted from the private and public resource:

$$\Pi_i = p\bullet\left(H_{EEZ,i} + H_{HS,i}\right) - C_i\left(E_{EEZ,i} + E_{HS,i}\right) \qquad (3)$$

[16] Note that the steady-state condition does not require diffusion to vanish but only to be balanced by growth and harvest in every zone.

where the first term captures revenues with p the (constant) fish price and $H_{EEZ,i}$ and $H_{HS,i}$ the harvest levels obtained by nation i from fishing in its own EEZ and in the high seas, and the second term represents the cost function which depends on inputs, i.e. efforts. Each player i has to make two strategic choices: the fishing effort in the own EEZ, $E_{EEZ,i}$, and the fishing effort in the high seas, $E_{HS,i}$.

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 voluntary and open to all nations as reflected by Article 8(3) of the UN Fish Stocks Agreement in 1995. Moreover, we assume that states which decide against membership in an RFMO cannot be prevented from harvesting.[17]

In order to capture these institutional features, we choose from the set of coalition formation games the single coalition open membership game due to d'Aspremont et al. (1983) which has been frequently applied in the literature on IEAs (e.g. Carraro 2000 and Finus 2003 for overviews) but also in other areas (e.g. Bloch 2003 and Yi 1997 for surveys). This coalition game is a two-stage game.

In the first stage, players decide upon their membership. Those players that join the RFMO form the coalition and are called members, those that do not join are called non-members and act as singletons. The decisions in the first stage lead to a coalition structure $K = \{S, \mathbf{1}_{\text{(N-n)}}\}$ where S is the set of n coalition members, $n \in \{0,1,...,N\}$, and $\mathbf{1}_{\text{(N-n)}}$ 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 model. In each stage, strategies (participation and fishing effort) form a Nash equilibrium. The game is solved backward.

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17 The legal basis and the implications of giving up this assumption are briefly discussed at the end of section 7.

In the second stage, given some coalition S has formed in the first stage, non-members act as singletons and maximize their individual payoff, Π_i, while members, acting like one player, maximize the aggregate payoff of their coalition, $\Pi_S = \sum_{i \in S} \Pi_i$:[18]

$$\underset{\left(E_{EEZ,j}, E_{HS,j}\right)}{\arg\max}\ \Pi_j\left(\boldsymbol{E}\right) \quad \forall\, j \notin S \tag{4}$$

$$\underset{\left(\boldsymbol{E}_{EEZ,S}, \boldsymbol{E}_{HS,S}\right)}{\arg\max}\ \Pi_S\left(\boldsymbol{E}\right) \tag{5}$$

where $\boldsymbol{E} = \left(E_{EEZ,1},...,E_{EEZ,N}, E_{HS,1},...,E_{HS,N}\right)$ denotes the vector of all fishing efforts whereas $\boldsymbol{E}_{EEZ,S} = \left(E_{EEZ,i}\right)_{i \in S}$ and $\boldsymbol{E}_{HS,S} = \left(E_{HS,i}\right)_{i \in S}$ denote the vectors of fishing efforts of the coalition members in the EEZs and in the high seas, respectively. The simultaneous maximization of (4) and (5) delivers the equilibrium fishing efforts $\left(E^*_{EEZ,j}, E^*_{HS,j}\right)$, $j \notin S$, and $\left(\boldsymbol{E}^*_{EEZ,S}, \boldsymbol{E}^*_{HS,S}\right)$. We call this a coalitional Nash equilibrium in order to distinguish it from an ordinary Nash equilibrium. However, note that the coalitional Nash equilibrium is identical to the Nash equilibrium if coalition S comprises only a single player, $S = \{i\}$, or is empty $S = \varnothing$. Moreover, if coalition S comprises all players, $S = \{1,...,N\}$, i.e. the grand coalition forms, the coalitional Nash equilibrium corresponds to the socially optimal fishing vector. Hence, the entire range from no cooperation, partial cooperation to full cooperation can be captured by this approach.

It is worthwhile to mention that the solution to (4) and (5) will be identical for every coalition $S \subseteq \{1,...,N\}$, i.e. the degree of cooperation does not matter, if and only if $\alpha = 0$ (no high seas) and all $d_{ij} = 0$ (no diffusion). That is, there is no externality across players. In contrast, even if all $d_{ij} = 0$, i.e. there is no diffusion between any zone, as long as $\alpha > 0$, there is an area of common property resource that can be exploited by all countries, no, partial and full cooperation imply different vectors of equilibrium fishing efforts. This is also true even if

[18] The assumption that RFMO-members choose their fishing efforts cooperatively, both in the high seas and in their EEZs, is in line with FAO (2010), p. 123, which states: "*Each RFMO is, inter alia, called upon to ensure that the management measures for the high seas segments of the resources and those measures for the intra-EEZ segments of the resources are compatible with each other*".

$\alpha = 0$, i.e. all property is privately owned, as long as there is diffusion among at least two zones, i.e. there exists at least one $d_{ij} > 0$, such that the action of one player has an impact on at least one other player.

Equilibrium efforts $\boldsymbol{E}^*(S)$ derived from (4) and (5) together with the steady-state conditions of stocks in (2) have to be inserted into the payoff function (3) to determine individual payoffs $\Pi^*_{j \notin S}(S)$ and the coalitional payoff $\Pi^*_S(S)$. The coalitional payoff will have to be distributed in some way such that $\sum_{i \in S} \Pi^*_i(S) = \Pi^*_S(S)$. For details see section 4.

Having determined equilibrium payoffs for every possible coalition structure in the second stage, we can now proceed to the first stage. In the first stage, a coalition S is considered to be stable if it fulfills the following two conditions:

Internal Stability:

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

External Stability:

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

Note that the grand coalition is externally stable by definition as there is no outsider left that could join the coalition. Moreover, the coalition structure of only singletons is stable by definition, which ensures existence of a stable coalition structure. This follows from the fact that this coalition structure can be supported by all players announcing not to be a member of the coalition, i.e. $S = \varnothing$, and hence a deviation by one player will make no difference.

4. Model Specification and Solving Procedure

4.1 Preliminaries

As mentioned above, the model is solved by backward induction. The most complex part relates to the second stage in which optimal fishing efforts have to be determined for a given coalition structure. For this, the system of equations (2), which represents the steady-state conditions, and the first-order conditions derived from (4) and (5) have to be solved simultaneously in order to obtain steady-state stocks and equilibrium fishing efforts. Due to the diffusion term, which links the steady-state stocks, we face a highly nonlinear system of $3N+1$ equations that cannot be solved analytically. Hence, we have to rely on numerical simulations.

It is evident that computing time and capacity requirements increase exponentially with the number of players. For this reason, we confine ourselves to the case of $N=3$ players. This is certainly the minimum number of players that makes the analysis of coalition formation interesting, but as it turns out, this is sufficient to derive interesting qualitative results. For $N=3$, we have to consider three possible coalition structures, namely the grand coalition, the two-player coalitions and the all-singletons coalition structure. Furthermore, we will restrict the analysis to symmetric parameter values for all players. This implies symmetric equilibria in the Nash equilibrium and the social optimum. Moreover, all possible two-player coalitions are equivalent with symmetric payoffs for coalition members (i.e. equal split of the total coalitional payoff), though they differ from the payoff of a non-member.[19] Moreover, with symmetry, internal and external stability are closely related (Carraro and Siniscalco 1993): if a coalition with n players is not internally stable, then the coalition with $n-1$ players is externally stable.

4.2 Functional Specification

In this section, we specify the functional relationships (Table 2). It will be apparent that the specifications follow the mainstream assumptions in the literature.

[Table 2 about here]

The most commonly used *growth function* (Table 2, first row) is of the logistic type where r denotes the intrinsic growth rate, which is assumed to be identical in all zones. Thus, r is our measure of rivalry with the degree of rivalry inversely related to the value of r (see Table 1).

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[19] Thus, players are ex-ante symmetric (before coalition formation) but may be ex-post asymmetric, depending on whether they become members or non-members. The assumption of ex-ante 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 1997 for an overview).

Regarding the *harvest function* (Table 2, second row), we have to bear in mind that in our base case, all countries are allowed to fish in the high seas whereas only the owner of an EEZ is allowed to fish in this territory. As commonly assumed, (total) harvest depends linearly on (total) fishing efforts and stock densities, with q denoting the catchability coefficient, a measure of the efficiency of the fishing fleet.

Two aspects need to be considered when specifying the *migration process*. 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: the EEZs are arranged in a circle with the high seas at its center, as depicted in Figure 1. This avoids boundary effects that would emerge with a linear arrangement and 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).[20]

[Figure 1 about here]

Second, we have to define what determines the *intensity of migration* between two neighboring fishing grounds. We assume a density-dependent diffusion process, i.e. the strength of migration between neighboring fishing grounds is given by the difference in stock densities, scaled by the product of the sizes of zones (Kvamsdal and Groves 2008, Table 2 third row).[21] This description of the diffusion process ensures the conservation of biomass in the absence

[20] Other possible arrangements as described in Sanchirico and Wilen (1999) include sink-source models which model dispersal as a unidirectional flow from a source to a sink and the fully integrated system in which all zones are directly connected to each other. The sink-source model, though it is relevant in the context of some specific fish species, would create some asymmetry which we try to avoid in this paper for analytical tractability. In contrast, the fully integrated system would preserve symmetry and might seem even more general at first sight. However, in the case of more than three players and hence $N+1>4$ zones, it is impossible to arrange all zones such that every pair of zones share a border (see Gonthier 2008). For our assumption of three players, our circular arrangement is identical to the fully integrated system.

[21] From the entries of the dispersal matrix D, as given in the third row of Table 2, the character of the dispersal process is not directly apparent. However, it can be easily shown that the resulting biomass flow from zone i to a neighboring zone j is given by $d\sqrt{k_i k_j}\left(\frac{X_i}{k_i}-\frac{X_j}{k_j}\right)$. This illustrates that the entries of the dispersal matrix, as specified in Table 2, do indeed imply a density dependent diffusion process.

of harvest and growth, i.e. whatever leaves zone i for zone j arrives in zone j without any losses. Furthermore, it reflects the assumption that the intensity and direction of dispersal only depends on the difference in stock densities and not on the location of a zone. The diffusion parameter d, which we assume to be identical for all diffusion processes (again reflecting symmetry), is an indicator for the intensity of diffusion and thereby a measure for the degree of technical non-excludability (see, e.g. Janmaat 2005).[22]

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 2, fourth row) depend linearly on extraction efforts, though they are strictly convex if expressed in terms of harvest levels where *c* is the (constant) marginal cost of fishing effort, which is assumed to be identical for all players in accordance with our assumption of symmetry.

4.3 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 only few parameters. The choice of parameter values follows good practice with an extensive sensitivity analysis as explained below and summarized in Table 3.

[Table 3 about here]

First note that all subsequent results only depend on what is commonly referred to as the 'inverse efficiency parameter' $\frac{c}{pqk_{tot}}$ (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.[23] 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 prohibi-

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22 The implication of the parameter d can be understood from considering a normalized example with carrying capacities $k=1$. If the stocks in two zones differ by a certain value δ, and if this difference is maintained by some means, then the amount of biomass that flows from one zone to the other in one period of time equals $d\delta$.

23 This is in line with the common normalization $k=1$ 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 $k=1$. See equation (1).

tive costs at which countries quit fishing are given by $c \geq 1$, irrespective of the scenario of cooperation, we have $c \in [0,1]$. In our simulations, we set the base case value to $c = 0.5$ and conduct a sensitivity analysis for two other values: $c = 0.25$ and $c = 0.75$. For the intrinsic growth rate r, we choose the commonly used base value $r = 0.5$ and consider two other values in a sensitivity analysis: $r = 0.25$ and $r = 0.75$.[24]

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 $d \to \infty$.[25] With respect to α, we cover the whole range $\alpha \in [0,1]$, with $\alpha = 0$ implying that the entire fishing area comprises only state-owned 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 3.2, equation (1)).

The primary interest in simulation runs A, B and C is to investigate the dependency of efforts, stocks and payoffs on the allocation parameter α and the diffusion parameter d, measuring the degree of socially constructed and technical excludability, respectively. By varying these parameters, we are able to capture a great variety of settings, covering all four categories of shared stocks (see footnote 10): transboundary stocks ($\alpha = 0$ and $d > 0$), straddling stocks and highly migratory fish stocks ($0 < \alpha < 1$ and $d > 0$) and discrete high seas stocks ($\alpha = 1$). We also capture the "boundary cases" of non-shared stocks ($\alpha = 0$, $d = 0$), i.e., stationary within EEZs, and the case in which the EEZ boundaries become irrelevant ($d \to \infty$).

In simulation run A, the values of the cost and growth parameter are set to their base values, i.e. $c = 0.5$ and $r = 0.5$. In order to check the robustness of the results, a sensitivity analysis

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24 Our base case values $c = 0.5$ and $r = 0.5$ are commonly assumed in the literature (e.g. Hannesson 1997 and Tarui et al. 2008). Note that a variation of the growth rate in the range $0.25 \leq r \leq 0.75$ (e.g. as considered in Nøstbakken 2006) already has a significant impact on the outcome in terms of payoffs. For instance, in models with only a single zone (e.g. Pezzey et al. 2000), which correspond to $\alpha = 1$ in our model, aggregate payoffs in the Nash equilibrium at a growth rate $r = 2/3$ are already as high as in the social optimum at $r = 0.5$.

25 Results for $d = d_{max}$ differ less than 5 % from the results in the limit $d \to \infty$, which can be calculated analytically. Moreover, note that strong diffusion makes the allocation of property rights, i.e. the value of α, irrelevant because all countries virtually exploit the same stock. Accordingly, all results converge towards the 'only high seas' limit ($\alpha = 1$) as d approaches infinity.

is conducted in simulation runs B and C, varying c while keeping r constant and vice versa. This also provides comparative static results with respect to c and r where the former may be viewed as an indicator of the economic attractiveness of fishing and the latter, as mentioned above, as an indicator for the degree of rivalry. All subsequent results are derived from all simulation runs as summarized in Table 3.

4.4 Qualifications

While our model is based on the most common assumptions in international fisheries (see, e.g. Stavins 2011), we are well aware that some aspects remain neglected (see, e.g. Clark 2010). With respect to resource characteristics, we do not deal with the age structure of the stock, possible predator-prey relations requiring a multi-species approach, or migratory patterns which are related to the life-cycle of a species. We also do not model the micro level of fishery policies and production, mainly related to the national implementation of cooperative or non-cooperative fishery policies and the production function of individual fishermen. Thus, we neglect issues like setup or fix costs, policy regulations like gear restrictions or allocation of tradable or non-tradable fishing quotas to individual fishermen, efforts to reduce by-catch, and port state measures to deter illegal, unregulated and unreported fishing. Essentially, national implementation is assumed to be efficient and perfectly enforceable in our setting. Concerning international fisheries management, our crucial assumption is that all countries both fish in their own EEZ and the high seas. This abstracts from the fact that some coastal states are not engaged in high seas fishing and that distant water fishing nations might operate in high seas areas not adjacent to their coastal waters.[26] It also means that coastal states do not sell their fishing rights to other fishing nations (access agreements). In line with Art. 87, UNCLOS 1982, we assume that non-RFMO members cannot be deterred from fishing in the high seas, covering an alternative scenario where exclusion is possible in a brief discussion at the end of section 7.

5 Results: Second Stage of Coalition Formation

In this section, we analyze how equilibrium fishing efforts, stocks and payoffs depend on the degree of cooperation and the crucial parameters of our model and how the various degrees

[26] However, note that we capture the cases where a stock occurs only within EEZs ($\alpha = 0$) or only in the high seas ($\alpha = 1$).

of cooperation compare to each other. This will also provide helpful information for the interpretation of the incentive structure to form stable coalitions as analyzed in the first stage of coalition formation in section 6. For notational convenience, we skip in the following the term "equilibrium". Unless otherwise stated, we always refer to efforts, stocks and payoffs in the respective equilibrium, no, partial and full cooperation, i.e. all singleton coalition structure, two-player coalition and grand coalition with three players. We may recall that the degree of socially constructed (technical) excludability, measured by the allocation parameter α (diffusion parameter d), is inversely related to the value of this parameter. The same holds for the degree of rivalry measured by the intrinsic growth parameter r.

Result 1: The Role of Socially Constructed and Technical Excludability under Full Cooperation (Social Optimum)

Under full cooperation, the total fishing effort, total stock and total payoff are independent of the degree of socially constructed excludability (allocation parameter α) and the degree of technical excludability (diffusion parameter d) where totals refer to aggregation over all players and zones.

In the social optimum, neither the distinction between high seas and EEZs matters for equilibrium strategies nor the level of diffusion. This is because in the social optimum externalities across all players are internalized, i.e. the social planner maximizes the aggregate payoff over all players and zones. Efforts are distributed such that effort densities, i.e. the efforts per area $E_{EEZ,i} / k_{EEZ}$ and $E_{HS,tot} / k_{HS}$ are equal everywhere, irrespective of d and α. Accordingly, stock densities $X_{EEZ,i} / k_{EEZ}$ and X_{HS} / k_{HS} are the same in every zone and independent of d and α.[27] In contrast, diffusion and the allocation of property rights matter under no and partial cooperation.

Result 2: The Role of Socially Constructed and Technical Excludability under No Cooperation (Nash Equilibrium)

Under no cooperation, individual and total fishing efforts increase in the allocation parameter α and the diffusion parameter d. Accordingly, the total stock in the entire fishing area

[27] Obviously, this result rests on the assumption of symmetry with respect to fishing areas and dispersal patterns. For asymmetry, an optimal fishing policy, i.e. the allocation of efforts, as well as resulting stock densities depend on the characteristics of fishing grounds and dispersal patterns (cf. Costello and Polasky 2008).

decreases in α and d. The individual payoffs of players and the total payoff over all players decrease in α and d.

At the aggregate level, a high value of α, i.e. a low degree of socially constructed excludability, aggravates over-exploitation and leads to lower stocks and payoffs. Similarly, the higher the diffusion between zones, i.e. the lower the degree of technical excludability, the more will the fish stock be exploited (high fishing efforts), resulting in low stocks. This translates into low individual payoffs and a low total payoff.

Whereas results at the aggregate level are clear-cut, a breakdown into efforts and stocks in the different zones reveals the complexity of the underlying incentive structure. Since the equilibrium fish stock density in the high seas is always lower than in the EEZs (due to more players fishing in the high seas), diffusion will always flow from the EEZs to the high seas. This encourages fishing in the high seas with fishing efforts increasing in the value of d. The mirror image is found in the EEZs which suffer from outgoing diffusion. However, the optimal equilibrium reaction does not follow a simple pattern. On the one hand, lower EEZ-fishing efforts preserve the own fish stock; on the other hand, higher EEZ-fishing efforts slow down diffusion to the common property high seas. These countervailing forces lead to some ambiguity in terms of equilibrium individual fishing efforts in the EEZ as a function of d which is not apparent at the aggregate level where total individual efforts clearly increase with increasing diffusion.[28]

Viewed together, the results illustrate that there is an interesting and subtle incentive structure when players behave non-cooperatively if zones are linked through diffusion. This complex incentive structure carries over to the situation where some players behave cooperatively, but not all, as considered under partial cooperation.

Result 3: The Role of Socially Constructed and Technical Excludability under Partial Cooperation

Under partial cooperation, coalitional fishing efforts decrease in the allocation parameter α but may increase or decrease in the diffusion parameter d. Fishing efforts of outsiders increase in α and d. The total effort in the entire fishing area increases in α and d.

[28] Also in Janmaat (2005) it is recognized that a density-dependent diffusion process can create a destructive incentive to overexploit one's own fishing grounds in order to attract incoming diffusion.

Accordingly, the total stock in the entire fishing area decreases in α and d. The individual payoffs of signatories and the total payoff over all players decrease in α and d, though the outsider's payoff increases in α and d.

A general conclusion from Result 3 is that partial cooperation shares many features with no cooperation, quite different from those under full cooperation. As long as not all externalities are internalized across all players, the strategic interaction between members and non-members implies that a low degree of socially constructed (i.e. high value of α) and technical (i.e. high value of d) excludability has a detrimental effect on the total stock and total payoff. This is because the outsider, who is in the position of a free-rider, benefits from increased diffusion. Free-riding is particularly attractive the larger the area of the common property resource (high value of α). It is exactly then when, in equilibrium, the coalition chooses low fishing efforts to preserve the common pool resource. Only the optimal reaction of the coalition as a function of the diffusion parameter d is less clear-cut. On the one hand, high diffusion encourages exploitation of the high seas through the coalition; on the other hand, the inflow from the high seas comes from two EEZs belonging exclusively to its members.

The strategic interplay between players is also evident from the following results which compare individual equilibrium fishing efforts (Result 4a), total equilibrium fishing efforts (Result 4b), and total equilibrium stocks and payoffs (Result 5) for the three scenarios of cooperation.

Result 4: Individual and Total Fishing Efforts under Different Degrees of Cooperation

a) Let the individual total fishing efforts in all zones under full, no and partial cooperation be denoted by E_i^F, E_i^N, $E_{i\in S}^P$, and $E_{i\notin S}^P$, respectively, with S denoting the set of coalition members, then $E_{i\notin S}^P \geq E_i^N \geq E_{i\in S}^P \geq E_i^F$ with strict inequalities whenever $\alpha > 0$ or $d > 0$.

b) Let the total fishing effort in the entire area under full, no and partial cooperation be denoted by E^F, E^N, and E^P, respectively, then $E^N \geq E^P \geq E^F$ with strict inequalities whenever $\alpha > 0$ or $d > 0$.

Compared to no cooperation, under partial cooperation the two-player coalition reduces its total fishing effort, being aware of the mutual externalities in the high seas, between coalition members' EEZs and between all these zones. However, the coalitional effort to preserve the fish stock under their control are thwarted by the free-rider whose total effort is increased compared to no cooperation. This "leakage effect" is due to the downward sloping reaction function of the coalition and of the outsider as fishing efforts are strategic substitutes as frequently observed in the context of public goods. However, despite this leakage effect, total fishing efforts decrease under partial compared to no cooperation. Technically, this implies that the slopes of the reaction functions are smaller than one in absolute terms.

As will be analyzed in section 6, the leakage effect is a driving force why self-enforcing cooperation proves difficult and will only be successful in a few cases. The next result compares fish stocks and payoffs at an aggregate level, resulting from fishing efforts under various degrees of cooperation. In order to measure the importance of cooperation as a function of our model parameters, we consider relative normalized differences (as absolute values have no sensible meaning in a stylized model) related to the benchmark full cooperation.

Result 5: Total Stocks and Payoffs under Different Degrees of Cooperation

Let the total fish stock in the entire area and the total payoff under full, no and partial cooperation be denoted by X^F, X^N, *and* X^P, *and* Π^F, Π^N *and* Π^P, *respectively, then*

a) $X^F \geq X^P \geq X^N$ *,and* $\frac{X^P - X^N}{X^F}$ *and* $\frac{X^F - X^N}{X^F}$ *increase in* α *and d;*

b) $\Pi^F \geq \Pi^P \geq \Pi^N$ *and* $\frac{\Pi^P - \Pi^N}{\Pi^F}$ *and* $\frac{\Pi^F - \Pi^N}{\Pi^F}$ *increase in* α *and d*

with strict inequalities under a) and b) if either $\alpha > 0$ *or* $d > 0$.

Result 5 stresses that already partial cooperation can improve upon no cooperation, not only in terms of payoffs but also in terms of stock levels (cf. Pintassilgo et al. 2010). Moreover, the importance of cooperation, either partial or full, increases with the degree of interconnectedness between players. That is, the importance increases the lower the degree of socially constructed and technical excludability, i.e. the higher the spatial allocation parameter α and the higher the diffusion parameter d are. In other words, if α and/or d are high, we would hope that full cooperation or at least partial cooperation is stable which is tested in section 6. In contrast for low values, cooperation does not matter much anyway.

The next result looks at the effect of a variation of the cost parameter c, reflecting the unit production cost of fishing, and the growth parameter r, our indicator of the degree of rivalry, reflecting by how much the stock recovers from fishing.

Result 6: The Role of the Cost and Growth Parameter under Different Degrees of Cooperation

a) Equilibrium efforts and payoffs decrease while stocks increase in the cost parameter c. This holds at the individual as well as at the aggregate level, irrespective of the allocation parameter α, the diffusion parameter d, and the degree of cooperation. The normalized differences $\frac{X^P - X^N}{X^F}$ and $\frac{X^F - X^N}{X^F}$ as well as $\frac{\Pi^P - \Pi^N}{\Pi^F}$ and $\frac{\Pi^F - \Pi^N}{\Pi^F}$ decrease in c whenever there is diffusion.

b) Equilibrium efforts and payoffs increase in the growth parameter r. This holds at the individual as well as at the aggregate level, irrespective of the allocation parameter α, the diffusion parameter d, and the degree of cooperation. Under full cooperation, equilibrium stocks are independent of r. Under no and partial cooperation the total stock increases in r whenever there is diffusion. The normalized differences $\frac{X^P - X^N}{X^F}$ and $\frac{X^F - X^N}{X^F}$ as well as $\frac{\Pi^P - \Pi^N}{\Pi^F}$ and $\frac{\Pi^F - \Pi^N}{\Pi^F}$ decrease in r whenever there is diffusion.

The intuition of Result 6a is straightforward. With increasing unit production costs, equilibrium fishing efforts are reduced, resulting in lower payoffs, though higher fish stocks. Thus from an ecological point of view, higher production costs help to preserve fish stocks but from an economic point of view it reduces economic rents. Shrinking rents under all scenarios of cooperation with increasing costs also implies that the relative differences in total payoffs between the two cooperative scenarios and the non-cooperative scenario become smaller. Thus, the need for cooperation decreases in the cost parameter c.[29]

Also Result 6b is in line with intuition. A high growth rate encourages fishing and is associated with an economic advantage. However, higher fishing efforts do not necessarily imply lower stocks as the resource recovers more quickly with a high growth rate r. Only if diffusion is irrelevant, e.g. there is full cooperation or the entire fishing area is public ($\alpha = 1$), a higher growth rate is exactly balanced by higher fishing efforts and hence the equilibrium stock remains constant.[30] However, if diffusion matters, e.g. there is no full cooperation, then the growth effect is stronger than the exploitation effect. Consequently, stocks and also payoffs increase with growth parameter r – our measure of rivalry and the need for cooperation decreases.

6 Results: First Stage of Coalition Formation

In this section, we analyze stability of coalitions. As noted above in subsection 3.3, the all-singletons coalition structure, corresponding to no cooperation or the Nash equilibrium, is stable by definition. Hence, we are interested whether and under which conditions full or partial cooperation could be a second equilibrium. We start by considering the first-best solution of full cooperation, corresponding to the social optimum.

Result 7: Stability of Full Cooperation

The incentive to leave the grand coalition is always positive, except for $\alpha = 0$ and $d = 0$, irrespective of the values of c and r. If $\alpha = 0$ and $d = 0$, however, there is no gain from cooperation. The incentive to leave increases in α and d.

Result 7 is discouraging. Not only because full cooperation is never stable but also because the free-rider incentive is particularly pronounced under those conditions when it would

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29 It may be worthwhile to recall that not the absolute value of c matters but the ratio c/pq. Thus, a higher c has the same effect as a lower price p or a lower catchability coefficient q, measuring the technological efficiency of harvesting fish. Hence, a high price and technological efficiency are detrimental to the ecological system but conducive to economic rents and make cooperation particularly valuable from a normative point of view.

30 Recall that we consider the steady state, where it can be shown analytically that the socially optimal fishing effort exactly offsets any increase in the growth rate. Note that in a fully fledged dynamic optimization setting, this does not necessarily hold any more. See footnote 13.

matter most. This follows immediately from Result 5, which states that cooperation would be most desirable in the case of a strong externality as expressed by a large share of the public domain, corresponding to a high value of α and a high diffusion coefficient d. It is evident that $\alpha = 0$ and $d = 0$ is a special case: there is no common property, and there is no diffusion between EEZs. Due to the lack of interdependency, there is no externality and hence full, no and partial cooperative fishing efforts coincide. Consequently, the incentive to deviate is zero but there is also no gain from cooperation. In a next step, we investigate whether partial cooperation can be stable.

Result 8: Stability of Partial Cooperation

The incentive to leave the two-player coalition is positive if either α or d are sufficiently large. However, for sufficiently small values of α and d, there is a range of parameter values for which partial cooperation is stable. This range increases in the cost parameter c and the growth parameter r.

In order to understand better the underlying driving forces of Result 8, Figure 2 has a closer look at the stability of a two-player coalition for various values of the parameters α and d. The fact that the grand coalition is never internally stable according to Result 7, allows us to conclude (for symmetric players) that a two-player coalition is always externally stable. Hence, Figure 2a focuses on internal stability. Internal stability holds for all parameter combinations for which the incentive to leave a two-player coalition is non-positive.

[Figure 2, a and b about here]

There are two countervailing effects. On the one hand, the larger α (d), the lower the degree of socially constructed (technical) excludability, the larger would be the gains from cooperation. On the other hand, with increasing α (d), also the incentive to deviate sharply increases, as already observed for the grand coalition in Result 7. Overall, a two-player coalition will only be internally stable, if α and d are sufficiently small.

A closer analysis of intermediate values illustrated in Figure 2b reveals that cooperation fails 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 ($r = 0.5$). The boundary value for d increases in c and r. Higher production costs discourage fishing (see Result 6a), and therefore lower the free-riding incentive and increase the upper bound of d for which partial cooperation is stable. Higher growth rates have a positive effect on stock levels (see Result 6b), and therefore lower free-riding incentives and hence also push the upper bound of d up for which partial cooperation is stable. Thus, the lower the degree of rivalry, the higher the likelihood of a stable coalition. However, even for high values of c and r, the range of stability remains rather small. Raising both base values of c and r from 0.5 to the maximum value 0.75 considered in our simulations, cooperation fails whenever $\alpha \geq 0.02$ and $d \geq 0.72$, corresponding to the larger triangle in Figure 2b.

7 Conclusions and Extensions

7.1 Preliminaries

In this section, we discuss our results by pulling the two stages of coalition formation together and relate them to a wider context. We first consider important aspects that follow from our positive analysis and then discuss some normative policy implications.

It is worthwhile to recall that our model formally captures various degrees of technical and socially constructed excludability, the degree of rivalry, as well the cost-price ratio, their impact on the absolute and relative differences between no, partial and full cooperation as well as their impact on the success of stable cooperative agreements. We could confirm the expectation that the higher the degree of excludability, the closer is the non-cooperative equilibrium to the social optimum and hence the smaller the gains from cooperation. However, in our non-cooperative coalition formation model we could show that full cooperation is not a stable outcome whenever cooperation matters. Hence, we analyzed the prospects of stabilizing a partially cooperative agreement. Our approach also facilitated to shed light on the discussion about the duality of public good and common games as discussed by Sandler and Arce (2003).

7.2 Benefit-Cost Duality of Public Good and Common Games

Sandler and Arce (2003) showed the duality between public goods and common pool resources but informally conjectured that it would be easier to establish joint action for the former than the latter. In our model the degree of rivalry is approximated through the growth rate r. Public good type of games, with a low degree of rivalry, are associated with high value of the parameter r, and common pool type of games, with a high degree of rivalry, are captured by a low value of the parameter r. In our model if the degree of socially constructed and technical excludability is not almost perfect, the most natural feature associated with the terms "public" and "commons", no cooperation is the only stable outcome, regardless of the value of r (Result 8). Hence, in terms of cooperation, the duality between public goods and common pool resources holds. However, in the only stable non-cooperative equilibrium, pay-offs and stocks increase with the growth rate r and the relative difference between no and full cooperation becomes smaller (result 6b). Hence, in terms of outcomes, this could be seen as confirming Sandler and Arce's conjecture. Similar, if we consider the limiting case in which the degree of socially and technical excludability is very high, then the duality may also break down: a high value of r may make partial cooperation possible whereas this may not be possible with a low value of r (Result 7). Again, with a high growth rate r, the relative difference between no and partial cooperation diminishes (Result 6b).

7.3 The Paradox of Cooperation

In his paper on international environmental agreements, Barrett (1994) coined the term "paradox of cooperation". He showed that whenever cooperation would be needed most from a global perspective, i.e. the relative difference in terms of global payoffs between the full and no cooperation is large, stable coalitions achieve relatively little. In Barrett's model, this difference is related to the benefit-cost ratio of providing the pure public good "emission abatement". In our model, something similar holds: the benefit parameter is de facto the price p and the cost parameter is c but also the catchability coefficient q. More specifically, we argued that only the ratio c/pq is important for results. We showed that the higher this ratio, the higher are stocks regardless of the degree of cooperation (Result 6a), the higher are the chances to establish at least partial cooperation (Result 8), but the lower are economic rents and also the need for cooperation (Result 6a). Historically, there is some evidence (Maguire et al. 2006) that the ratio c/pq has fallen in the course of the last century. In fact, most fish prices have gone up due to scarcity and technical and economic efficiency of production has improved tremendously, suggesting increasing values of q and lower values of c over time. Our results suggest that this could have aggravated the problem of overfishing – fish stocks have fallen and the need for cooperation has increased but the chances of establishing partial cooperation have deteriorated.

Because our model is richer that than Barrett's model, we could also test the paradox of cooperation regarding other dimensions. Partial and full cooperation would make a substantial difference compared to no cooperation whenever the public domain of the resource is larger (large values of α) and the migration of fish stocks is large (high values of d) (Result 5). However, exactly under these conditions not even partial cooperation is stable (Result 8), letting alone full cooperation (Result 7). Given this paradox of cooperation, one may derive some comfort from Results 2 and 3 which show that payoffs and stocks under no and partial cooperation decrease in α and d. Hence from a global perspective, one would hope for small values of α and d as this has a positive effect on payoffs and stocks and increases the chances of at least partial cooperation.

The performance of some international fishery agreements are well in line with our model predictions. The poor performance of most tuna-related RFMOs, such as the International Commission for the Conservation of Atlantic Tunas (ICCAT), represents a good example of failing cooperation (e.g. ICCAT 2009 and IOTC 2009). Failure occurs in the context of highly migratory species (which most tuna species are) and fishing areas that comprise a large portion of the high seas. In contrast, cooperation has been more successful in regulating the fish stock of the Alaska Pollock in the Bering Sea, which migrates to the aforementioned "Donut Hole", and the Norwegian spring spawning herring, which migrates in the Northeast Atlantic through the EEZs of several countries and the aforementioned "Banana Hole" in the high seas. Both species are more stationary and the portion of the high seas populated by these species is relatively small. Also from a survey on empirical bioeconomic studies, Bjørndal and Martin (2007) derive factors that impair the success of RFMOs, among those a high rate of migration of fish stocks, and a high share of the stock that migrates in the high seas. Similar conclusions emerge from econometric study by McWhinnie (2009) based on economic and biological data of more than 200 stocks around the globe.

Finally, our results indicate that the higher the growth rate (which is inversely related to the degree of rivalry), the less vulnerable a stock is to overexploitation and the higher are economic rents irrespective of cooperation (Result 6b; see also, e.g. FAO 2010). Hence, economic and ecological interests coincide. Moreover, the higher the growth rate, the higher are the chances to establish partial cooperation (Result 8). Despite this, the paradox of cooperation does not completely disappear as the need for cooperation becomes smaller with a high growth rate (Result 6b). The econometric study by McWhinnie (2009) suggests that the overexploitation of fish stocks goes along with low reproduction rates.

7.4 Policy Conclusions

Since a high ratio c/pq is conducive to establish RFMOs, narrows the gap between full, partial and no cooperation, but has a negative impact on payoffs, policy conclusions are not straightforward. Technical progress, probably fostered by more competition in the fishery sector, will most likely continue to push for a lower c and higher q in the long term. Hence, as far as the prospects of cooperation are concerned, input subsidies or price guarantees should be avoided. Raising costs (or lowering the net price of fish) through the auctioning fishing quotas or imposing a tax (e.g. landing fee) seem obvious measures to increase the ratio c/pq but would have to be accompanied by some form of lump-sum payment in order to avoid negative impacts on payoffs. However, even this conclusion may be premature as it does not address the question of how such a policy can be implemented self-enforcingly if a RFMO does not comprise all fishing nations.

Though the degree of technical excludability is given, this is different for the degree of socially constructed excludability. Our results suggest that the declaration of EEZs was a sensible step in alleviating the tragedy of the commons in fisheries, at least if fish stocks are not highly migratory. Further expansion of these zones may be worthwhile to consider. Whether such an expansion would receive sufficient political support in an amended UN Convention is difficult to predict. In our simple model, the endogenous choice of α could be modeled by a voting procedure preceding stage 1 and 2. Analytically, two cases can be distinguished. Case 1: if all parameters except α are such that partial cooperation cannot be stable anyway (sufficiently large d; small c/pq and r; see Result 8), all players would vote for $\alpha = 0$ as payoffs under no cooperation decrease with α (Result 2). Case 2: if partial cooperation is possible, then coalition members prefer $\alpha = 0$ but the free-rider prefers the maximum value of α which is still small enough such that the stability of the coalition is not jeopardized (Results 3 and 8). On which of the proposals players will agree in this case depends on the voting rule. For instance, under unanimity voting, free-riders would have veto power and could block any value of α below their optimum. Hence, not the entire fishing ground would be privatized.

Finally, there have been continues 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.

First, note that equilibrium fishing efforts, stocks and payoffs remain unaffected under full cooperation (as there are no outsiders to be excluded), as well as under no cooperation (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 partial cooperation where we have to set $E_{HS,j} = 0$, $j \notin C$ 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 the grand coalition and a two-player becomes less attractive. Moreover, the aggregate payoff of a two-player coalition is larger with than without exclusion.

Result 9: 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 (modification of Result 8);

b) the grand coalition is stable for a wide range of parameter values (Result 7 does not hold any more);

c) *the parameter space for which partial and full cooperation is stable increase with* α *(Result 7 and 8 are reversed);*

d) *if* α *is sufficiently small and the degree of technical non-excludability is high (high values of* d *) neither full nor partial cooperation may be stable (in line with Result 7 and 8). However, there always exists a value of* α *above which partial or full cooperation is stable (different from Result 7 and 8).*

These results are illustrated in Figure 3 which shows the areas in parameter space for which the two-player and the grand coalition are stable.

[Fig. 3 about here]

Clearly, the possibility to evict non-cooperating fishing nations from the high seas is beneficial for the stability of cooperation. Not only partial but also full cooperation is possible. Interestingly, the role of the allocation parameter α is reversed. Without exclusion, already partial cooperation fails whenever α is sufficiently large, whereas with exclusion, even the grand coalition turns out to be stable whenever α is sufficiently large. This is not surprising as a large common pool area (high values of α) implies large exclusive benefits to coalition members but low free-riding benefits to outsiders if exclusion is possible. Thus, if the recurrent attempts to make RFMO membership mandatory are successful, privatizing large portions of the high seas would be contra-productive. The larger the degree of technical non-excludability, the larger should be the area managed by the RFMO. Obviously, this scenario assumes a substantial amount of enforcement-power of RFMOs, most likely an overly optimistic view regarding future enforcement of international law.

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Table 1: Classification of Impure Public Goods

		high ← **Excludability** → low		
		low ← **Model Parameters** α, d → high		
low ← Rivalry → hHigh	**high ← Model Parameter** r **→ low**	private goods		common pool resources
			international fisheries	congestible public goods
		club goods		public goods

Table 2: Functional Specification of Model

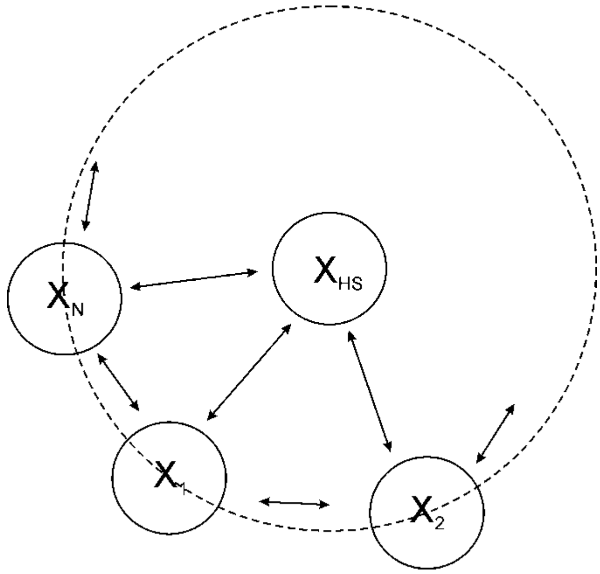
1) Growth Functions	$G_i\left(X_i\right) = rX_i\left(1-\dfrac{X_i}{k_{EEZ}}\right)$, $i = 1,\ldots,N$; $G_{HS}\left(X_{HS}\right) = rX_{HS}\left(1-\dfrac{X_{HS}}{k_{HS}}\right)$
2) Harvest Functions	$H_{EEZ,i}\left(X_i\right) = qE_{EEZ,i}\dfrac{X_i}{k_{EEZ}}$, $i = 1,\ldots,N$; $H_{HS}\left(X_{HS}\right) = q\sum_{i=1}^{N} E_{HS,i}\dfrac{X_{HS}}{k_{HS}}$
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	$C_i(E_{EEZ,i}) = cE_{EEZ,i}$, $i = 1,\ldots,N$; $C_i(E_{HS,i}) = cE_{HS,i}$, $i = 1,\ldots,N$
r = intrinsic growth rate; X_i, X_{HS} = stock in EEZ_i and HS, respect.; k_{EEZ}, k_{HS} = carrying capacity in EEZ and HS, respect.; q = efficiency parameter; $E_{EEZ,i}$, $E_{HS,i}$ = efforts in EEZ_i and HS, respect.; d = universal diffusion parameter; c = cost parameter.	

Table 3: Simulation Runs*

Simulation Runs	c	r	d	α
A	0.5	0.5	**0 – 1.28**	**0 – 1.0**
B	**0.25 - 0.75**	0.5	**0 – 1.28**	**0 – 1.0**
C	0.5	**0.25 - 0.75**	**0 – 1.28**	**0 – 1.0**

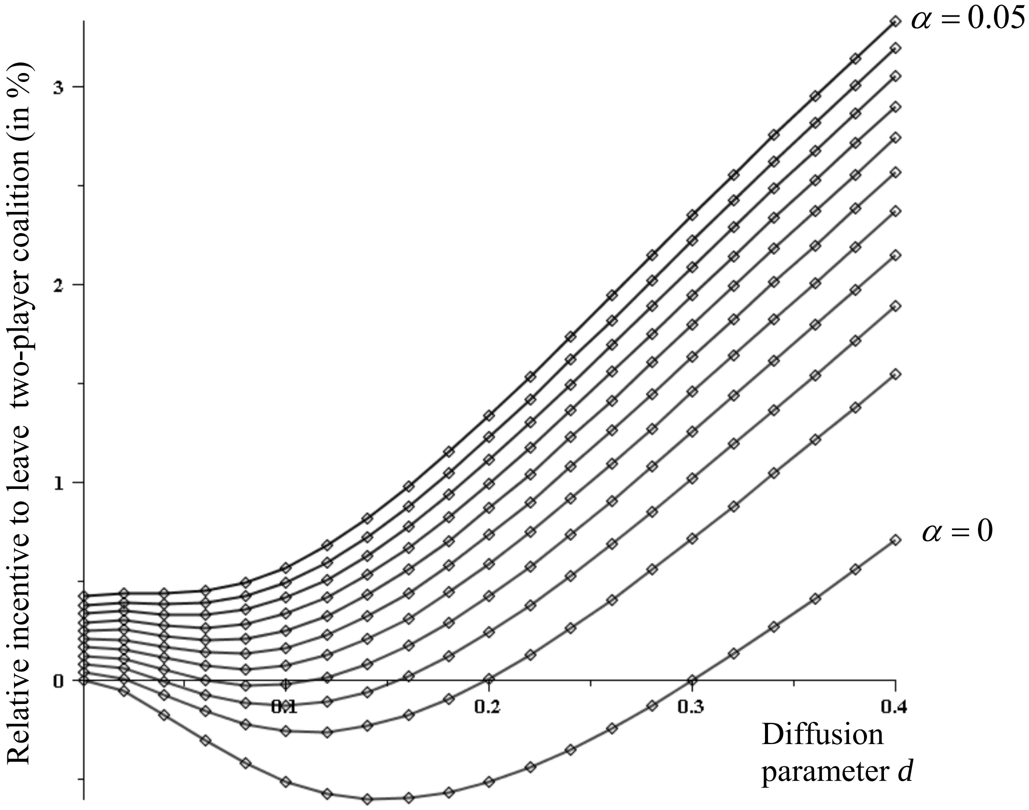
* Parameter variations in a simulation run are indicated bold; $p = 1$, $q = 1$ and $k_{tot} = 4$ are assumed throughout.

Figure 1: Migration Pattern and Spatial Allocation of Property Rights*



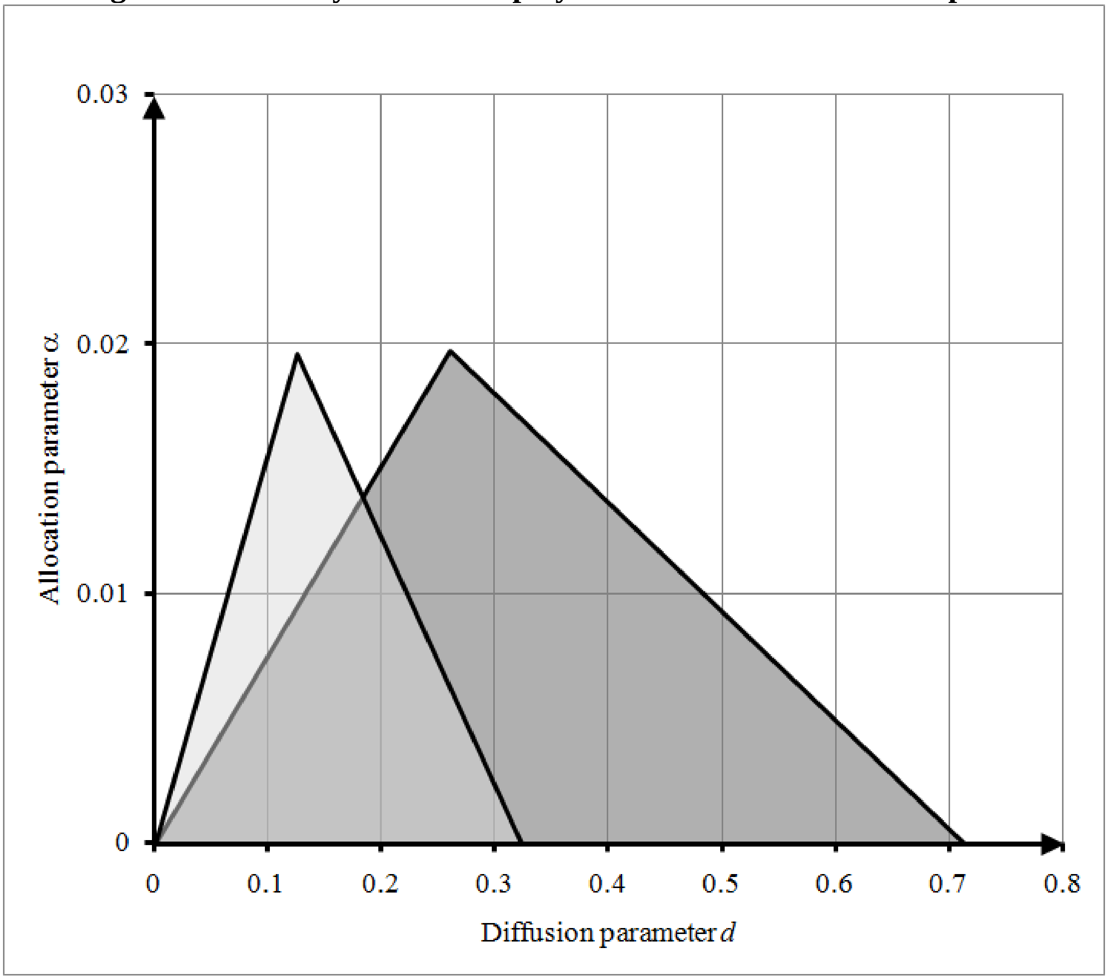
* Arrows indicate potential dispersal

Figure 2a: Incentive to Leave a Two-player Coalition*



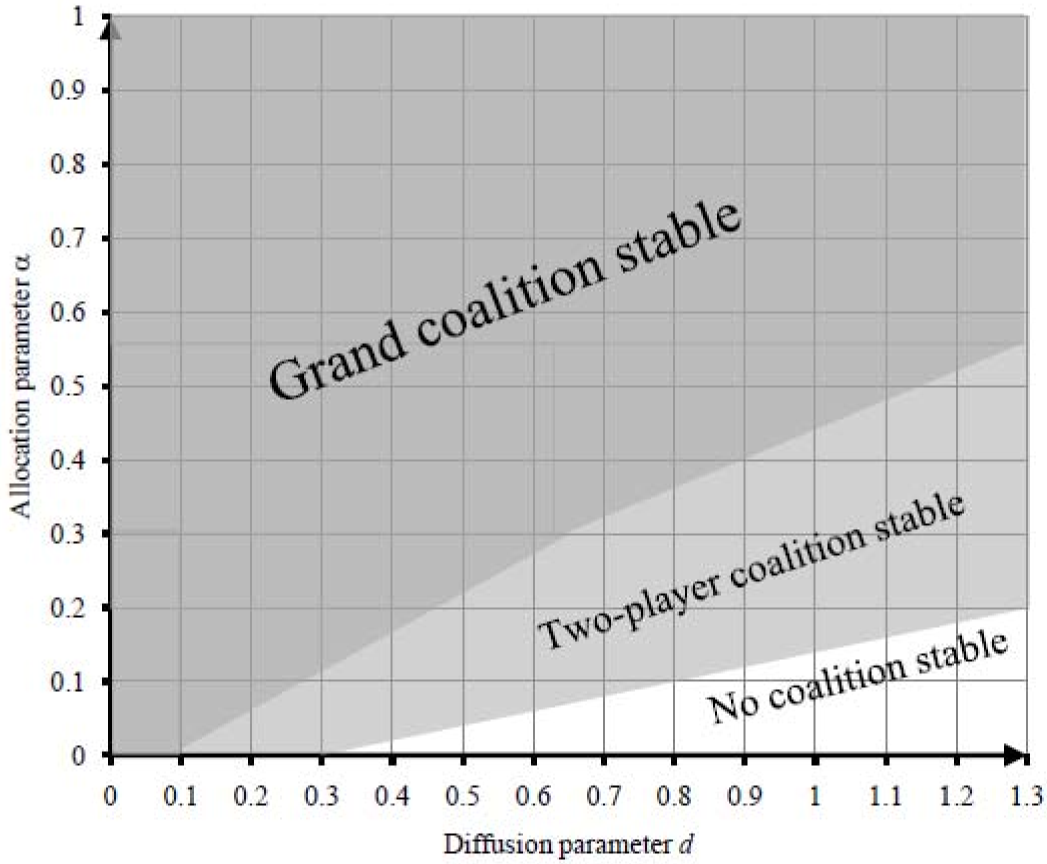
* The incentive to deviate is expressed as a fraction of the payoff of a coalition member. i.e. $\left[\Pi_i^*(C \setminus \{i\}) - \Pi_i^*(C) \right] / \Pi_i^*(C)$. For the cost and growth parameter base case values are assumed ($c = 0.5$ and $r = 0.5$).

Figure 2b: Stability of the Two-player Coalition in Parameter Space*



* Both triangles define parameter combinations (d, α) for which the two-player coalition is stable. The smaller, light shaded triangle refers to base case values for the cost and growth parameter ($c = 0.5$ and $r = 0.5$) whereas the larger, dark shaded triangle corresponds to the conditions that are most favorable for cooperation ($c = 0.75$ and $r = 0.75$).

Figure 3: Stability of Coalitions in Parameter Space with Exclusion*



* The shaded areas indicate parameter combinations (d, α) for which the respective coalition is stable if exclusion of non-members from fishing in the high seas is possible. Note that whenever the grand coalition is stable, the two-player coalition is *externally* unstable. Base case parameter values are assumed throughout ($c = 0.5$, $r = 0.5$, $p = 1$, $q = 1$ and $k_{tot} = 4$).