Property Rights vs. Cooperative Agreements on the Global Ocean Commons

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Abstract. Collective action for managing the world's ocean fisheries relies on two main types of institution, property rights (exclusive economic zones), which are established in customary law, and cooperative agreements (regional fisheries management organizations), which are established in treaty law. In this paper I develop a model in which both institutions emerge as equilibrium outcomes of an ocean fisheries game. I show that, as a general matter, both institutions help to limit overfishing of highly migratory stocks but that neither institution alone, nor both together, can suffice to overcome collective action failures on the global ocean commons.

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1. Introduction

Collective action at the international level is supported by two main kinds of institution, customary law and treaties. Customary law determines the background rules of the game; treaties are developed to address specific problems requiring collective action. Customary law applies universally; treaties apply only to the countries that consent to be bound by them. Customary law emerges spontaneously; treaties are negotiated explicitly. Customary law changes rarely; treaties are negotiated and renegotiated all the time. Many papers have modeled treaties as devices for bringing about collective action, implicitly taking customary law as a given.[2] In some situations, however, customary law not only changes, but does so for the same reason that treaties are created and modified: to support collective action. In this paper I model one such situation: the use of customary law and treaties to overcome the tragedy of the commons in the world's oceans.[3]

Creation of the Exclusive Economic Zone, or EEZ, marks one of the most significant developments in the history of property rights. The EEZ emerged from a process by which a coastal state would assert an exclusive right to fish within a certain distance from its shore and other states would either recognize the claim as being legal, usually by asserting the same right, or denounce the claim as being illegal. Contemporaneous with these developments, property rights to the oceans were also discussed in a series of Law of the Sea conferences. These were complementary processes. Spontaneous behavior by countries acting unilaterally revealed that there would be change. The conferences provided a forum for coordinating choice of a limit and for negotiating a grander bargain over related issues, such as freedom of

[2] For example, the extensive literature on international environmental agreements (for surveys, see Finus 2001; Wagner 2001; Barrett 2003; and de Zeeuw 2015) implicitly assumes that compliance is guaranteed—an assumption that is consistent with the customary principle known as *pacta sunt servanda* (treaties are binding).

[3] See Libecap (2014) for a recent survey of the literature on "global environmental externalities," including a discussion of the special problems posed by highly migratory fish species, the focus of my paper.

navigation and access to resources that lay beneath the seafloor, beyond the continental shelf. Ultimately, the 200-mile limit came to be codified in the Law of the Sea treaty, adopted in 1982, but it was enshrined in customary law long before this agreement entered into force in 1994, and is recognized as applying universally and not exclusively to the parties to this agreement. For example, the United States, a non-party to the Law of the Sea Convention, proclaimed a 200-mile conservation zone in 1976 and, more importantly, a 200-mile exclusive economic zone in 1983, indicating that it recognizes the 200-mile limit as applying in customary law (Henkin 1984: 1564).

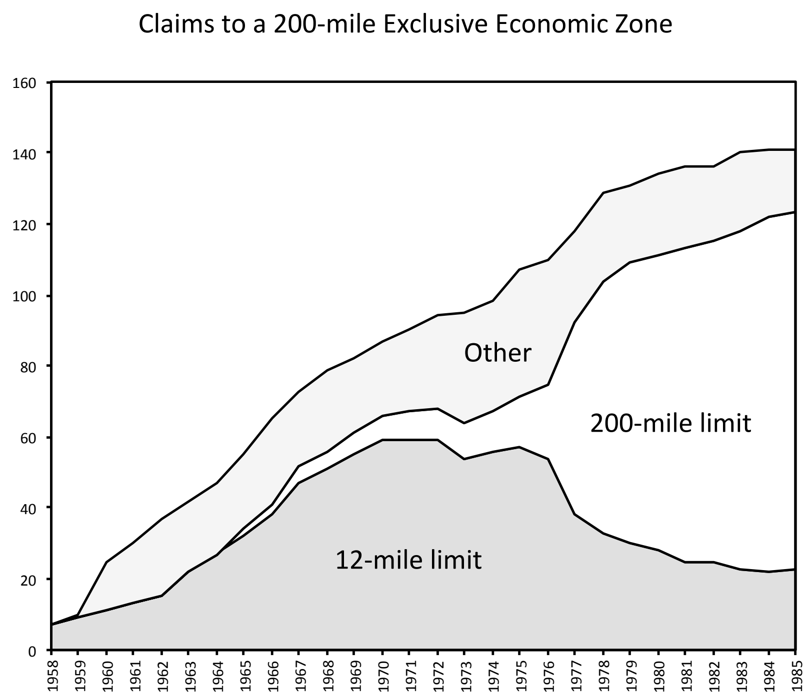
As shown in Figure 1, in a matter of just a few years (the most intense period being the mid-to-late 1970s), rights to a significant fraction of the ocean's fishery resources changed hands. Before this time, fish found in waters beyond the three-mile territorial limit belonged to any country that took the trouble to catch them. After this time, fish found within 200 miles of shore belonged exclusively to the coastal states that claimed this limit.[4]

A customary law exists when states behave in accordance with the law, and do so because they believe they are legally obligated to behave in this way (Bodansky 1995). How to distinguish any kind of equilibrium behavior from a customary law when beliefs must be inferred? International legal scholars have appealed to game theory to explain whether customary law really exists and, if so, how it works. Goldsmith and Posner (1999) argue that behaviors arising from self-interest have been misinterpreted as representing customary law. They also claim that customary law, being the product of a decentralized process, is incapable of solving any kind of collective action problem at the multilateral level. Norman and Trachtman (2005)

[4] The 200-mile limit is an upper bound and applies only where states assert this right. At the same time as the EEZ was created, the limit of the territorial sea was extended from three to 12 miles. As shown in Figure 1, some states claim only the 12-mile territorial limit, not an EEZ. Other states claim a different limit, usually because the distance between their shore and that of their oceanic neighbors is less than 400 miles. Note that archipelagic states are able to claim a right to the waters that connect their islands, irrespective of the breadth, essentially expanding upon the normal 200-mile limit.

disagree, arguing that customary law provides a real service to multilateral collective action by coordinating equilibrium selection in a repeated prisoners' dilemma.

Figure 1



Source: Compiled using data from Smith (1986).

Although their interpretations of customary law differ, both pairs of authors assume that countries have Nash conjectures (that is, each player chooses how to act assuming that other countries will not change how they act in response), which is inconsistent with the way customary law works. Here I model custom differently. In my model, every country believes that, should it deviate from an established custom, and should this deviation ultimately be considered lawful, other states will follow suit (if other states do not follow suit, the deviation would not be considered lawful). Under this assumption, the reason no country deviates from an established custom (in equilibrium) is that none wants to establish a precedent that allows *other* countries to deviate from the custom. This assumption, I show, supports an outcome that is very different from the one arising from Nash conjectures. Custom is not just a name given to equilibrium behavior. Nor is it merely a coordinating device. Custom acts as a significant restraint on behavior.

What is the mechanism that causes customary law to change? Verdier and Voeten (2014) argue that changes in customary law result from “tipping” behavior, a line of reasoning that is very sensitive to the specification of heterogeneous preferences. My model suggests a simpler explanation. Assuming symmetric players, I find that changes in customary law occur abruptly when the value of an exogenous variable crosses a critical threshold. Below the threshold, one property rights regime is adopted; above the threshold, another regime is adopted. My model also identifies the variable that causes this shift: the number of distant water states wanting to enter the fishery.

A reading of the history of ocean property rights confirms the importance of this variable. Chile moved first by claiming a 200-mile “exclusion zone” in 1947 as “Chile’s infant whaling industry found itself threatened by ever increasing levels of competition from efficient distant water whaling fleets” (Hollick 1977: 497). Peru and Ecuador quickly followed Chile’s lead “to protect their fishing fleets” at a time when “the prospect of American tuna fishing in waters off their shores was growing” (Hollick 1977: 499). These early claims failed to attract international acceptance, but they inspired Iceland to declare a four-mile fishery limit in 1952, a 12-mile limit in 1958, and a 50-mile limit in 1972, moves that were taken because “overfishing by foreign fleets was depleting a natural resource on which [Iceland’s] economy depended for survival” (Mitchell 1976: 128). Iceland’s claims sparked a series of conflicts with the United Kingdom, all of which were resolved through bilateral agreements, and none of which presaged a change in custom. However, by the time Iceland declared a 200-mile EEZ in 1975, provoking a third Cod War with the United Kingdom, many other countries had already claimed a 200-mile limit, and it was clear that customary law was about to change. In 1976, countries attending the fourth session of the Third Law of the Sea Conference accepted that coastal states had the right to declare an EEZ, and from that moment onwards there was no turning back. Indeed, the United Kingdom extended its own Exclusive Fisheries Zone from 12 to 200 miles in 1977.[5] Within a year or so, property rights to the world's oceans underwent an unprecedented and relatively sudden regime shift.

Another fascinating feature of the EEZ is that its precise value, 200 miles, is arbitrary, having no basis in ecology, economics, or legal precedent.[6] In my model, this feature also emerges very naturally: the equilibrium EEZ, determined in the context of customary law, is either zero or a strictly positive value that is bounded but of indeterminate value. This implies that the 200-mile limit was chosen for its "focal" qualities (Schelling 1960).

Even before the EEZ was created, countries had developed cooperative arrangements, known as Regional Fisheries Management Organizations or RFMOs. Today there are about 17 such organizations, two of which were established before creation of the EEZ. In contrast to the property rights regime, which consists of a general set of rules, these cooperative arrangements, established by international agreements or treaties, are specific either to all fish stocks found in a particular sea (such as the Northwest Atlantic) or to particular, highly migratory species found throughout an ocean (such as tuna in the Indian Ocean).

Like all treaties, fisheries agreements are binding only on the countries that consent to be bound by them, and states can easily get around a treaty's rules by not participating (that is, by declining to join up in the first place or by withdrawing sometime after becoming a party). Similarly, private operators can get around a treaty's rules by switching registration of their vessels to non-parties (reflagging). Other, more general treaties have been adopted to try to constrain *these* behaviors.

[5] The United Kingdom did not formally declare an EEZ until 2013, but this was only because the British Parliament had other priorities (Kvinikhidze 2008).

[6] To underscore the arbitrariness of the 200-mile value, Hollick (1977) provides evidence showing that the 200-mile zone first asserted by Chile was based on a false understanding of legal precedent. See also Hannesson (2006).

In particular, the "Fish Stocks Agreement" requires that states "pursue cooperation in relation to straddling fish stocks and highly migratory fish stocks either directly or through [established RFMOs]." However, like the fisheries agreements themselves, the Fish Stocks Agreement applies only to the states that consent to be bound by it. Even if states adhere to this agreement, they may make their participation in an RFMO conditional on collective decisions being made by consensus (essentially giving each member a veto) or allowing individual members to "object" to (that is, opt out of) proposals to limit their harvests. RFMOs may be able improve on purely non-cooperative behavior, but the requirement that agreements be self-enforcing severely limits what RFMOs are able to achieve. I show that fisheries agreements can sustain full cooperation only when the number of states having access to the fishery is very small (specifically, no greater than four). In oceans having many coastal states and/or open to entry by distant water states, my model predicts that free riding behavior will be very difficult to suppress.

In my model, property rights and cooperative arrangements play different but complementary roles. Cooperative agreements limit the effort (or harvest) levels of the states that participate in them, taking the total number of states having access to the fishery as given, whereas property rights arrangements may be used to limit access by distant water states. I also identify another, less obvious role played by customary law: preventing coastal states from claiming a property right when it is in their collective interests not to do so.

My model provides a coherent perspective for evaluating a range of proposals for improving governance of the global ocean commons. One such proposal is to require that states fishing in an ocean become members of the corresponding RFMO—essentially, making the Fish Stocks Agreement apply in customary law. I show that, even if this requirement were somehow enforced externally, it would have little if any effect on overfishing, as it would merely shift the burden of enforcement from participation (unregulated fishing) to compliance (illegal fishing). (According to the model, the problem isn't that compliance would fall but that restrictions on effort would have to be relaxed in order to assure full compliance.) A second proposal is to extend today's EEZ so as to eliminate the high seas. Doing this would transfer fishing rents from distant water to coastal states, but it would not address the need for coastal states to cooperate in managing their common property. A third proposal is to retain the current EEZ limit but ban fishing on the high seas. I find that this proposal, though supported by recent research (White and Costello 2014), is the worst of all remedies. Like the previous one, it fails to address the need for coastal states to cooperate, but it also raises costs by constraining where coastal states may fish.

Before proceeding, I should underscore that my aim here is not to develop a general theory of the choice of an EEZ; my focus is only on highly migratory stocks, and creation of the EEZ was motivated by other considerations, including management of near-shore and demersal fisheries, in addition to being determined in a setting in which other issues (such as the right of passage) were also being decided. As well, my analysis leaves out many details that would be relevant to a more focused analysis of a particular RFMO or fishery, such as the options for adopting trade (port state) measures.

After presenting the basic model in the next section, the paper proceeds in stages. I first study a "closed" ocean with no institutions. I then allow coastal states to form an international agreement and to establish property rights. Later in the paper I extend this analysis to an "open" ocean. The final section discusses the implications of the paper for ocean governance.

2. Model

In standard fisheries economics, the only dimension modeled explicitly is time. There is no space; the fishery inhabits a point. Previous papers have modified the standard model by assuming that the fishery consists of multiple points or "patches" (Sanchiricho and Wilen 1999, 2005), all of which are linked by diffusion equations that specify the movement of fish between the points. White and Costello (2014) and Finus and Schneider (2015) have adapted this approach to ocean fisheries, letting some "patches" represent EEZs and a residual one the high seas. However, all of these approaches lack a true geography. In this paper I take a different approach. I abandon dynamics and make the ocean a line, essentially swapping a time dimension for a spatial one.[7] In particular, I make the ocean a circle, and assume that coastal states, represented by points, or "homeports," are distributed equidistant from one another around the circle. With these assumptions, the model is fully symmetric, the number of coastal countries can take on any integer value, and the size of the ocean can be varied continuously.[8]

It might seem more natural to model the fishery in two (or even three) spatial dimensions. However, no single, two-dimensional representation can yield valuable general results. For example, if the ocean were represented by a two-dimensional circle, and the territories of states were represented by segments along the circumference of the circle, extensions of coastal states' territories would look like pie slices, becoming narrower as the limit of the EEZ was extended, and EEZs do not typically look like this (see, for example, the EEZs of the United States shown in Figure 2). Similarly, rectangular oceans would give states situated in the corners different oceanic territories than states situated on the sides, violating the symmetry assumption. The assumption that fishing occurs on a line avoids these problems.

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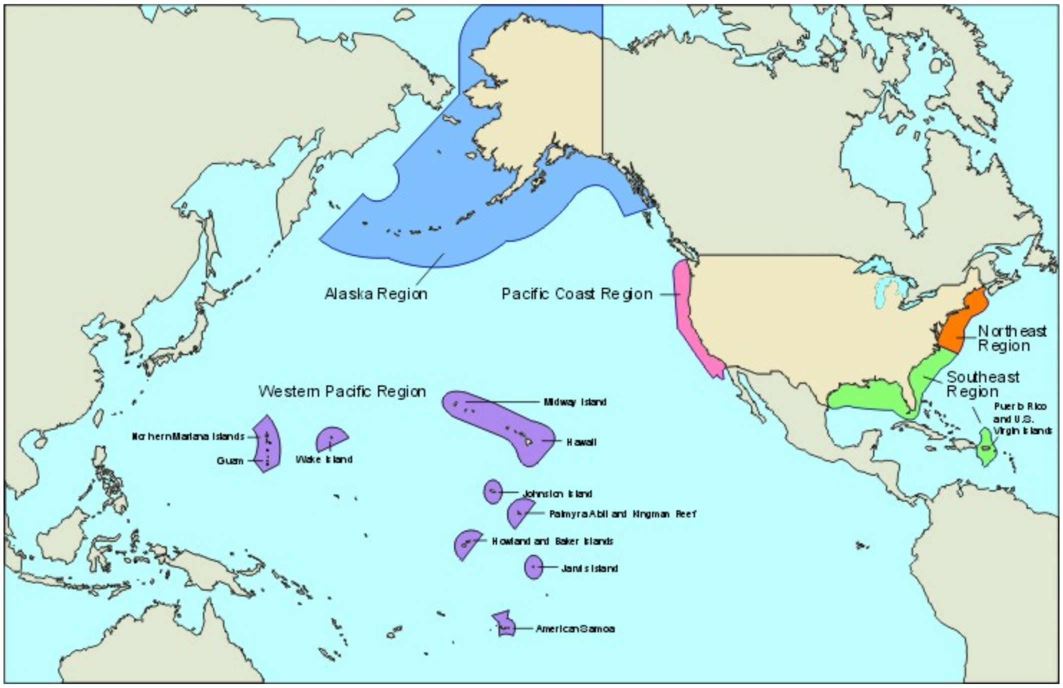
[7] Gordon's (1954) classic paper is also static, and also concerned with collective action on the commons, though his focus was on a demersal species with a fixed location. Scott (1955) emphasized the need to take the dynamics of a fishery into account, an approach that was later developed with more rigor by Clark and Munro (1975), Clark (1976), and others. Munro (1979) and Levhari and Mirman (1980) were the first to model the transboundary management problem as a non-cooperative game, though they focused on the dynamic aspects of competition between only two players; for reviews of the more recent literature, see Bailey, Sumaila, and Lindroos (2010) and Hannesson (2011). My model of "geography" was inspired by Hotelling's (1929) classic paper on competition on "Main Street," though in my model the players do not choose their location on the line; their location is fixed. The players in my model choose where to fish on the line.

[8] Finus and Schneider (2015) assume that each EEZ zone is connected to two neighboring EEZ zones and to the high seas, making their ocean akin to a two-dimensional circle, though in their model there are no homeports and there is, thus, no distance variable.

Figure 2
The Exclusive Economic Zones of the United States



Source: http://www.afsc.noaa.gov/generalinfo/eez.htm.

Let L represent the length of the ocean. Since the ocean is assumed to be a circle, the ocean's length is equivalent to the circle's circumference; that is, $L \equiv 2\pi r_0$, where r_0 represents radius. Assuming that there are n coastal states, each represented by a point on the circle (interpreted as the state's homeport), the assumption that coastal states are equidistant from one another implies that the distance between any two neighboring countries is L/n. An important choice for every coastal state is the distance it chooses to fish. Denote the distance fished by country i, d_i, and assume (for convenience) that all countries must fish in a clockwise direction. With freedom of the high seas, and there being no EEZ, $d_i \in [0, L]$.

Another important assumption concerns the distribution of fish on the line. For simplicity, I assume that the stock is distributed uniformly throughout the ocean (that is, on the line). The uniformity assumption holds roughly for species like tuna that are "highly migratory" (Block *et al.* 2005). It implies that, as fish are harvested along any segment of the line, the stock will be reduced everywhere on the line to maintain uniformity of the distribution. As my model is static, stocks are best interpreted as steady state values.[9]

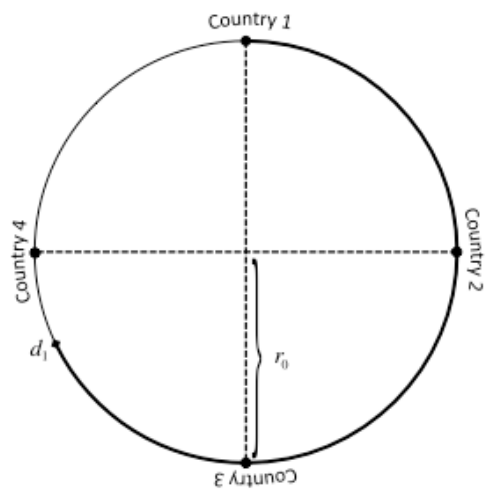
Letting x denote the fish stock, the uniformity assumption implies that the stock available to country i is given by $x_i = xd_i/L$. If i fishes a greater distance from its homeport, it has access to a greater portion of the total stock. Freedom on the high seas and no EEZ implies that every coastal state can potentially fish throughout the ocean. However, d_i is a choice variable, and countries may prefer to fish within only parts of an ocean.

Figure 2 illustrates the fishery assuming $n = 4$. In this figure, Country 1 fishes to a distance d_1 from its homeport, a length between one-half and three-quarters of the ocean. If this were a symmetric solution, each country would fish the same distance, meaning that most of the ocean would be fished by three out of four coastal states, the rest by just two coastal states.

[9] To relate this static model to a dynamic counterpart, divide a circular ocean of given size into W patches of equal carrying capacity (if the ocean has capacity K, each patch has capacity K/W). Identify each patch by a distinct integer (1, 2, . . . , W – 1, W), and arrange these equidistantly around the circle such that, moving in a clockwise direction, patch 2 comes after 1, patch 3 comes after 2, and so on until patch W, which follows W – 1 and is followed in turn by patch 1. Next, specify identical diffusion equations (with diffusion depending on the distance between patches, and with distance depending on the size of the ocean and the number of patches) that move fish (at some rate) from the patches in which stocks are more abundant to neighboring patches in which stocks are less abundant. My assumption that the stock is distributed uniformly on the line is roughly equivalent to assuming that W is very large.

Figure 2

A closed ocean shared by four countries



Country *i*'s harvest, h_i, is assumed to depend on its fishing effort, E_i, and the stock available to it by virtue of its choice of distance:

$$h_i = \frac{\alpha E_i d_i x}{L}. \tag{2.1}$$

Eq. (2.1) tells us that, to obtain a positive harvest, a state must not only deploy a positive amount of effort. It must also deploy this effort over a positive distance from its homeport.

Assuming logistic growth in the stock, and interpreting x to be a steady state value, we have

$$h = \sum_i h_i = rx\left(1 - \frac{x}{K}\right), \tag{2.2}$$

where r denotes the intrinsic rate of growth of the stock and K is carrying capacity.

Substituting (2.1) into (2.2) and rearranging gives

$$x = K\left(1 - \frac{\alpha}{rL}\sum_i E_i d_i\right). \tag{2.3}$$

Every coastal state *i* must choose a level of effort, E_i, as in the usual fishery model, and a distance, d_i, from its homeport over which it applies this effort.

Costs are assumed to be given by

$$C_i = \left(c + \gamma d_i\right)E_i. \tag{2.4}$$

If distance is given, the term in parentheses is just a constant, and (2.4) reduces to the standard assumption in the literature that costs are proportional to effort. The parameter *c* captures the fixed cost of fishing effort. You can think of this as the cost of boats sitting in the homeport. The novelty in (2.4) is the spatial dimension of costs, represented by the variable d_i.[10]

It will be useful to consider the implications of these assumptions. According to eq. (2.1), for any given stock, a one percent increase in either effort or distance will increase a country's harvest, and therefore its revenues, by one percent. Eq. (2.4) shows that a one percent increase in effort will also increase costs by one percent, but that a one percent increase in distance will increase costs by *less* than one percent. Taken together, (2.1) and (2.4) thus imply that it will always pay a country to fish a greater distance than to add more effort. The reason a country will add

[10] The cost function assumed here has the virtue of being simple, but of course other relations could be considered. For example, we could assume that marginal distance costs increase with distance; $C_i = \left(c + \gamma d_i^v\right)E_i, v > 0$. Alternatively, we could retain the assumption of constant marginal distance cost but assume that $d_i \in \left[0,\, d^{\max}\right]$, implying that distance is constrained by technology rather than by international law or the size of the ocean.

more effort is that distance is constrained, either by the size of the ocean or by the country's access to the ocean as determined by the EEZs chosen by other countries.

3. The Closed Ocean

Assume to begin that the ocean is "closed" in the sense that fishing is restricted to coastal states. Coastal state *i*'s profit (rent) from fishing is

$$\Pi_i = ph_i - C_i, \tag{3.1}$$

or, upon substituting,

$$\Pi_i = \frac{p\alpha E_i d_i K}{L}\left[1-\frac{\alpha}{rL}\left(E_i d_i + \sum_{j\neq i} E_j d_j\right)\right] - \left(c+\gamma d_i\right)E_i. \tag{3.2}$$

Assume now that every country i maximizes (3.2) by choosing $E_i \geq 0$ and $d_i \in [0, L]$, taking as given all E_j, d_j, $j \neq i$. Differentiating (3.2) with respect to E_i and assuming an interior solution yields

$$E_i = \frac{rL}{\alpha(n+1)d_i}\left(1-\frac{L(c+\gamma d_i)}{p\alpha K d_i}\right). \tag{3.3}$$

For any positive distance, effort will be positive so long as the term in brackets is positive. This term is increasing in distance. Throughout this paper, I assume that it will always pay a coastal state to fish within its own line segment (that is, eq. (3.3) is strictly positive for $d_i = L/n$). As the second order conditions are satisfied, eq. (3.3) yields the Nash equilibrium effort level for given distance.

Maximization of (3.2) by choice of d_i requires, for an interior solution (but see below),

$$d_i = \frac{rL}{\alpha(n+1)E_i}\left(1-\frac{\gamma L}{p\alpha K}\right). \tag{3.4}$$

The optimal distance will be positive so long as the term in brackets is positive—that is, so long as, when the stock is at carrying capacity, fishing a short distance from the homeport is profitable. Again, this condition is sure to hold for any fishery of interest.

However, eqs. (3.4) and (3.3) cannot hold simultaneously, meaning that there cannot exist an interior solution for distance. As noted previously, the most efficient way for a state to increase its harvest is to fish a greater distance (where this is possible) rather than to increase effort, which involves a fixed cost. The optimal distance is thus the maximum distance,

$$d_i^* = L. \tag{3.5}$$

Given this distance, the optimal effort has to be adjusted accordingly, by substituting (3.5) into (3.3):

$$E^* = \frac{r\theta}{\alpha(n+1)}, \tag{3.6}$$

where

$$\theta \equiv \left[1-\frac{(c+\gamma L)}{p\alpha K}\right]. \tag{3.7}$$

Assume $\theta > 0$ (later I shall strengthen this assumption). Then we have:

Proposition 1. *In a closed ocean, the "tragedy of the commons" affects fishing effort, not where states choose to fish*.[11]

As we shall see, this proposition anticipates much of what follows in this paper. If overfishing is due to excessive effort, and not "excessive distance," limiting where states fish cannot limit the tragedy of the commons directly; it can only do so indirectly.

How serious is the tragedy of the commons? From (3.6) we see that, as the number of countries fishing in the ocean increases, aggregate effort increases, even as each state cuts back on its own fishing effort. In the limit as $n \to \infty$, the aggregate level of effort approaches twice the efficient level. This limit value represents the outcome associated with "open access."

Finally, upon substituting we get the full cooperative and non-cooperative payoffs,

$$\Pi^{FC} = \frac{prK\theta^2}{4n}, \tag{3.8}$$

$$\Pi^{NC} = \frac{prK\theta^2}{(n+1)^2}. \tag{3.9}$$

From these equations we see that the fraction of the full cooperative payoff that is sustained by non-cooperation declines with *n*, approaching zero as *n* gets very large (see the curve on the left side of Figure 3; the other curves are discussed later).

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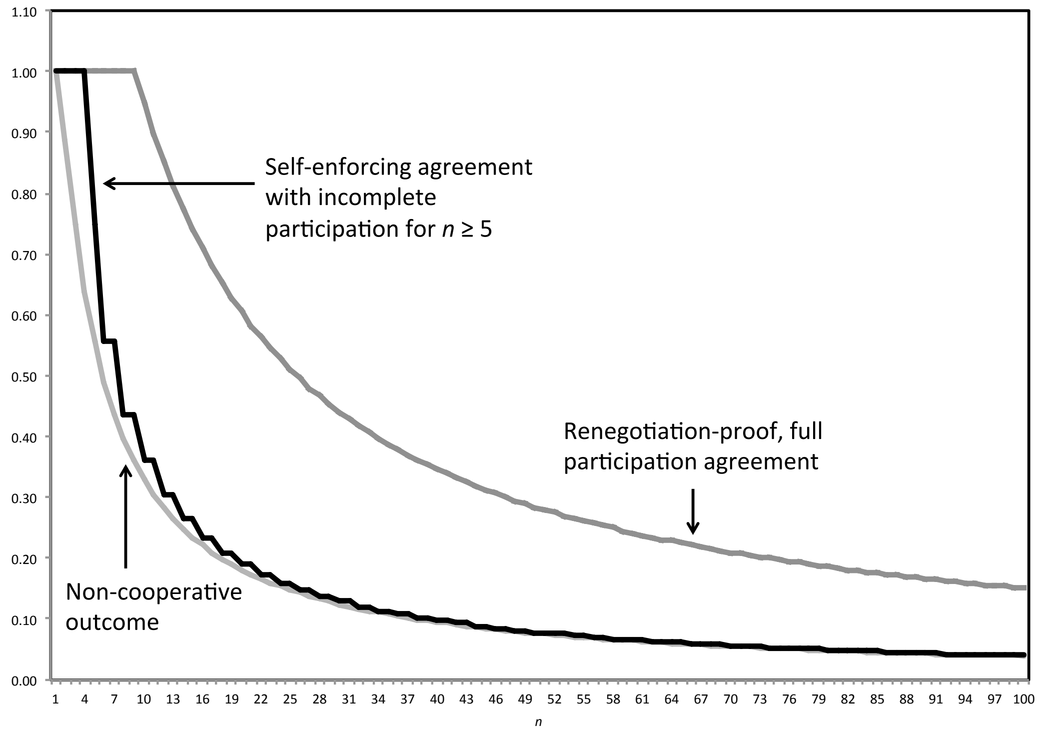
[11] This result does not depend on costs being linear. For example, using the cost function presented in footnote 10, there exists an interior solution in which distance is equal to $d_i^* = \left(c/\gamma(\nu-1)\right)^{1/\nu}$.

Figure 3

Fraction of the full cooperative payoff sustained by non-cooperation and different conceptions of a cooperative agreement for *n* from 1 to 100



4. International fisheries agreements in a closed ocean

In this section I model an international fisheries agreement in the manner of an international environmental agreement.[12] In this model, n coastal states play a three-stage game.[13] In Stage 1, each country chooses whether or not to participate in an agreement to limit effort; in Stage 2, parties to this agreement choose their effort levels collectively; and, finally, in Stage 3, non-parties choose their effort levels. The resulting agreement is self-enforcing in the sense that: (1) given the participation decisions of other countries, no party can gain by withdrawing from, and no non-party can gain by acceding to, the agreement; (2) the parties cannot gain collectively

[12] For a different approach to the formation of a fisheries agreement, see Pintassilgo (2003).
[13] See, for example, Barrett (2003). Note that I am not allowing the parties to an agreement to choose port state measures or trade restrictions.

by rewriting their agreement; and (3) the non-parties cannot gain individually by changing their effort levels, given the effort levels chosen by all the other countries.

Given that the tragedy of the commons affects effort rather than distance, we can substitute (3.5) for d_i. Suppose that there are k signatories and, thus, $n - k$ non-signatories. Each non-signatory is assumed to choose its effort level so as to maximize its payoff, taking as given the behavior of all other countries. This yields, for the ith non-signatory, the effort level

$$E_i^n = \frac{1}{(n-k+1)}\left(\frac{r\theta}{\alpha} - kE^s\right) \tag{4.1}$$

Notice that (4.1) and (3.6) are equivalent if there are no signatories (that is, if $k = 0$).

Signatories will choose their effort levels so as to maximize their collective payoff. Dropping subscripts, signatories will choose E^s to maximize

$$\Pi^s = kp\alpha KE^s \left\{\theta - \frac{\alpha}{r}\left[kE^s + (n-k)E^n\right]\right\}. \tag{4.2}$$

Remembering that maximization of (4.2) requires anticipating how non-signatories will respond to the choice of signatories' effort, we get

$$E^s = \frac{r\theta}{2\alpha k} \tag{4.3}$$

Setting $n = 1$ in (3.6) yields the effort level for the sole owner. This is the efficient aggregate effort level for the fishery (Scott 1955). Hence, (4.3) implies:

Proposition 2. *Members of a self-enforcing fisheries agreement always choose the collectively optimal level of effort. Free riders (if any) apply more effort on top of this, giving rise to the tragedy of the commons.*

Since the aggregate amount of fishing effort by cooperating countries is independent of the number of cooperating countries (and the number of non-cooperating countries), as more states join an agreement the pre-existing members cut back on their effort to accommodate the new entrants. Eq. (4.3) thus gives expression to the so-called "new entrant problem" (Munro 2007). Existing members of an agreement would rather that other countries not join the agreement, but they would also rather that these other countries not fish in the first place. Why should existing members reduce their effort level to build up a fishery if the result is that other states will enter the fishery, taking away the hard won surplus created by the original members? In the above model, this behavior arises from the assumption that the signatories choose their effort level taking participation as given.[14]

Substituting (4.3) into (4.1) gives

$$E^n = \begin{cases} \dfrac{r\theta}{2\alpha(n-k+1)} & \text{for } k = \{1,2,\dots,n-1\} \\ \dfrac{r\theta}{\alpha(n+1)} & \text{for } k = 0. \end{cases} \tag{4.4}$$

Comparing (3.6) with (4.4), we see that signatories use their leverage to impel non-signatories to reduce their effort, relative to the non-cooperative outcome. However, as k increases (starting from k = 1), each signatory's level of effort falls and each

[14] This, of course, is the classic Nash assumption. To allow signatories to choose their effort level anticipating how membership will change as a consequence, we can invoke the concept of a "far-sighted" equilibrium; see Chwe (1994). For an application to international fisheries, see Walker and Weikard (2016).

non-signatory's level of effort rises. The effort of each signatory exceeds that of each non-signatory for $(n+1)/2 > k \geq 1$, whereas for

$$n-1 \geq k > (n+1)/2 \tag{4.5}$$

the effort of each non-signatory exceeds that of each signatory.

Substituting (4.3) and (4.4) into (3.2) we obtain the payoffs to signatories and non-signatories for various values of *k*:

$$\Pi_n(k) = \begin{cases} \dfrac{rpK\theta^2}{(n+1)^2} & \text{for } k = 0 \\ \dfrac{rpK\theta^2}{4(n-k+1)^2} & \forall k \in \{1,\dots,n-1\} \end{cases} \tag{4.6}$$

$$\Pi_s(k) = \frac{rpK\theta^2}{4k(n-k+1)} \forall k \in \{1,\dots,n\}. \tag{4.7}$$

An agreement is self-enforcing so long as no signatory can gain by withdrawing from, and no non-signatory can gain by acceding to, the agreement:

$$\Pi_s(k) \geq \Pi_n(k-1) \text{ and } \Pi_n(k) \geq \Pi_s(k+1). \tag{4.8}$$

Substituting (4.6)-(4.7) into (4.8) gives

$$\Pi_s(1) \geq \Pi_n(0) \Rightarrow (n-1)^2 \geq 0 \tag{4.9}$$

$$\Pi_s(k) \geq \Pi_n(k-1) \Rightarrow (n-k+2)^2 \geq k(n-k+1) \forall k \in \{2,\dots,n\} \tag{4.10}$$

$$\Pi_n(k) \geq \Pi_s(k+1) \Rightarrow (k+1)(n-k) \geq k(n-k+1)^2 \; \forall k \in \{2,...,n-1\}. \tag{4.11}$$

Condition (4.9) obviously holds, as is to be expected, since the model allows signatories to commit to an effort level in a way that is not possible for non-signatories. The other two conditions are more interesting. Note first that, if (4.10) holds for $k = n$, then the full cooperative outcome can be sustained by a self-enforcing agreement. In such cases, (4.11) can be ignored. Upon setting $k = n$ in (4.10) we find that that this condition holds for $k \leq 4$.

Solving the quadratic constraints in (4.10) and (4.11), we get

$$\frac{5+3n-\sqrt{n^2-2n-7}}{4} \geq k^* \geq \frac{1+3n-\sqrt{n^2-2n-7}}{4} \; \forall n \geq 5. \tag{4.12}$$

Condition (4.12) yields an interior solution in which some, but not all, countries participate in the international fisheries agreement.[15] Plugging in values for n shows that, for n = 5, we have k^* = 4; for n = 10, $k^* = 6$; and for n = 100, $k^* = 51$. In the limit as $n \to \infty$, $k^* \to 1 + n/2$; that is, in the limit as $n \to \infty$, $k^*/n \to 1/2$.

It can also be shown that, when (4.12) holds, condition (4.5) is satisfied; that is, when participation in a self-enforcing international fisheries agreement is incomplete, each signatory expends less fishing effort than each non-signatory. Furthermore, as n gets very large, the effort levels of both signatories and non-signatories converge to the non-cooperative levels. Payoffs also converge to the non-

[15] It is interesting to observe that membership in a self-enforcing fisheries agreement depends only on n and not on the other parameters. In the literature on international environmental agreements, the reverse is usually the case: the equilibrium participation level is typically independent of n, but may depend on other parameters (Barrett 2003).

cooperative levels (see the two curves on the left side of Figure 3).[16] As *n* increases beyond four, the effect on payoffs is dramatic. When *n* exceeds seven, for example, rents to the fishery are less than half the full cooperative level and exceed the non-cooperative level by just a slim margin.

To understand how the model works, imagine that there exists a "baseline" set of countries, n_0, and that the members of n_0 have all chosen in equilibrium whether to cooperate or free ride. Now add another country, and suppose that the "original" countries maintain their status as cooperators or free riders (if any). How will the "new" country behave? It can join either the "original" cooperators or the free riders (if any). If the new country joins the cooperators, the original members of this group will reward this move by reducing their effort (in this case, *n* and *k* both increase by one, and as shown by eq. (4.4), the free riders will not change their effort). If the new country joins the free riders, the original members of *this* group will reduce *their* effort (in this case, as shown by (4.3), the cooperators will not change their effort). It can also be shown that when $n_0 \leq 3$, the new country will always want to cooperate; when $n_0 = 4$, the new entrant will want to free ride; and when $n_0 \geq 5$, the choice made by the new entrant will alternate between being a free rider when n_0 is odd and a cooperator when n_0 is even. The reason is that, when n_0 is very small, the addition of a new cooperating country causes the original cooperating countries to reduce their fishing effort substantially (for example, if n_0 equals one, and a new country joins, the incumbent will reduces its effort by half). However, the original signatories reduce their effort by less and less as each new country joins up. Eventually, once n_0 equals four, the new country does better by free riding. From this point on, the payoff to joining one group rather than the other is more finely balanced, and will seesaw with every incremental increase in n_0, making it in the

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[16] The figure shows $\left[k\Pi^s(k)+(n-k)\Pi^n(k)\right]/\left[n\Pi^s(n)\right]$. Substituting (3.9) and (3.10), this expression becomes $\left[1+(n-k^*)/(n-k^*+1)\right]/(n-k^*+1)$. Of course, the values for k^* can be taken from (3.15). As k^* depends only on *n*, the figure applies very generally.

interest of each new additional country to alternate between joining one group and the other.

Summarizing, we have:

Proposition 3. *In a closed ocean, a self-enforcing international fisheries agreement can sustain the full cooperative outcome for* $n \leq 4$.[17] *For* $n \geq 5$, *membership in such an agreement will be incomplete, total effort will exceed the full cooperative level, and non-signatories will apply more effort than signatories. In oceans with many coastal states, a cooperative agreement will do little to reduce overfishing, barely improving on the non-cooperative outcome.*

5. Members-only fishing

Proposition 2 tells us that overfishing is due entirely to fishing by non-members, a phenomenon known as "unregulated" fishing. This suggests that the obvious way to limit overfishing is to require that *every* state participate in the relevant fishery agreement—that is, that adherence to the UN Fish Stocks Agreement should be universal, as advocated by the Global Oceans Commission (2014).

How to model this? It might seem that we need only set the payoff of every non-signatory equal to zero for any *k*. Doing so would impel every coastal state to join the RFMO, and thus (given other assumptions in the model) sustain full cooperation. However, the above model assumes that compliance with the RFMO's rules is full, and this assumption only makes sense when a country can easily avoid the need to comply by withdrawing from the agreement. If it is determined (outside of the model) that non-members of the RFMO forfeit the right to fish, compliance by RFMO members would need to be made endogenous. Universal adherence to the UN Fish

[17] In the literature on international environmental agreements, full cooperation can be supported by two, three, or a variable number of countries, depending on the nature of the payoff function (Barrett 2003).

Stocks Agreement thus wouldn't make free riding disappear; it would simply shift the burden of enforcement from deterring non-participation to deterring non-compliance. In the fisheries jargon, it would transform a problem of "unregulated" fishing into one of "illegal" fishing.

Although the preceding analysis is static, it contains a kind of built-in reciprocity. It assumes that, should any country withdraw from the self-enforcing agreement, the remaining cooperators will "respond" by increasing their effort levels. In particular, the cooperating players as a group are assumed to choose their effort levels to maximize their collective payoff, both on and off the equilibrium path—an assumption that, in a repeated game context, makes the agreement strongly renegotiation-proof (Farrell and Maskin 1989). Indeed, taking discount rates to be close to zero, it can be shown that the strongly renegotiation-proof equilibrium of the infinitely repeated game corresponds to the one we obtained before for the static game: full cooperation can be sustained as an equilibrium only for $n \leq 4$.[18]

To accommodate full participation for *any n*, we clearly have to modify this model's assumption about equilibrium and out-of-equilibrium behavior. Suppose, then, that cheating by country *j* in some period triggers a punishment phase in which every other country *i*, $i \neq j$, adopts an effort level E_i^j. Suppose also that if *j* should make amends by playing E_j^j in the punishment phase, cooperation by the entire group will eventually be restored, giving *j* an average payoff of $\bar{\Pi}$ (taking discount rates to be close to zero, this value will equal the per-period payoff to cooperating). For such

[18] To see this, suppose country *j* cheats, triggering punishment by the other countries. The best these $n - 1$ other countries can do in the punishment phase is to play (4.3). If *j* plays $E_j^j = 0$ to make amends, the other countries therefore earn the full cooperative payoff in the punishment phase, and so cannot do better by renegotiating. In the punishment phase, it must also be the case that *j* is at least as well off making amends than by behaving differently. If *j* makes amends, cooperation will be restored, and *j* will earn an average payoff of $\bar{\Pi}$. If *j* fails to make amends, the best *j* can do is to play (4.4) for $k = n - 1$, giving the payoff $\Pi = pKr\theta^2/16$. Country *j* cannot do better than to make amends provided that $\bar{\Pi} \geq pKr\theta^2/16$. Substituting (3.8) for $\bar{\Pi}$, we see that full cooperation can be sustained as a renegotiation-proof equilibrium for $n \leq 4$.

an agreement to be weakly renegotiation-proof, it must be the case that, given punishments E_i^j, country *j* cannot do better than to make amends as prescribed by the agreement so as to restore cooperation:

$$\max_{E_j} \Pi_j \left(E_j; E_i^j\right) \leq \bar{\Pi}. \tag{5.1}$$

It must also be the case that, when *j* plays E_j^j, each of the other countries is at least as well off playing E_i^j as failing to punish *j*:

$$\Pi_i \left(E_i^j; E_j^j\right) \geq \bar{\Pi}. \tag{5.2}$$

Note that, with this formulation, the cooperating players cannot renegotiate the punishment written into their agreement; they can only choose whether or not to abide by their agreement.

The solution to the LHS of (5.1) is the same as (4.1) for $k = n - 1$. Upon substituting, (5.1) becomes

$$\frac{prK}{4}\left[\theta - \frac{\alpha\left(n-1\right)E_i^j}{r}\right]^2 \leq \bar{\Pi}. \tag{5.3}$$

If (5.3) holds, country *j* cannot do better except by making amends for violating the agreement. Let us assume that "making amends" means that *j* must choose $E_j^j = 0$. Inequality (5.2) then becomes

$$p\alpha KE_i^j\left[\theta - \frac{\alpha\left(n-1\right)E_i^j}{r}\right] \geq \bar{\Pi}. \tag{5.4}$$

Setting the above inequalities equal to one another to solve for E_i^j and then substituting gives the maximum payoff that can be sustained by *n* countries:

$$\bar{\Pi} = \frac{4pKr\theta^2}{(n+3)^2}. \tag{5.5}$$

Comparing this value to the full cooperative payoff given by (3.8), we have:

Proposition 4. *A full-participation, weakly renegotiation-proof agreement can sustain the full cooperative outcome for n ≤ 9; for n ≥ 10, such an agreement sustains less than full cooperation, with the ratio* $\bar{\Pi}/\Pi^{FC}$ *declining towards* Π^{NC}/Π^{FC} *as n increases.*[19]

This equilibrium concept sustains greater cooperation than the one used before for *n* ≥ 5, because it allows harsher punishments. Once *n* becomes big enough, even this concept can't sustain full cooperation. However, the concept can sustain *some* cooperation by *all* countries. By reducing the *depth* of cooperation (that is, by letting participants cooperate less than fully), the agreement is able to increase the *breadth* of cooperation (the participation level). To illustrate, an agreement with 15 parties (the current size of the Antigua Convention, which replaced the agreement creating the Inter-American Tropical Tuna Commission or IOTC) can sustain a payoff that is three-quarters the size of the full cooperative level. An agreement with 50 parties (the current size of the International Commission for the Conservation of Atlantic Tunas or ICCAT) can sustain a payoff about one-quarter as large as the full cooperative level. In fisheries policy circles, the emphasis is put on "unregulated" and "illegal" fishing, but this analysis reveals another way in which free riding can be expressed: weak RFMO obligations.

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[19] Both payoff ratios approach zero in the limit as $n \to \infty$.

As Figure 3 shows, all countries (on average) do at least as well with a full-participation, weakly renegotiation-proof agreement as with a self-enforcing agreement (in the sense defined in the previous section), implying that all countries should *want* to embrace the UN Fish Stocks Agreement.[20] However, the punishments in the full participation agreement are less credible than the ones in the self-enforcing agreement, and countries cannot "choose" credibility. A fairer comparison may be between the self-enforcing agreement modeled previously and a full participation agreement (for $n \geq 5$) that merely codifies the non-cooperative outcome. Indeed, the tuna agreements with the highest membership levels (ICCAT, with 50 members, and the IOTC, with 32 members) allow members to "object" to any proposed recommendation (such as a catch or effort limit), a procedure that allows any party to behave as it would do if it were a non-member and yet still retained the right to fish.[21]

6. Fishing in a closed ocean with a given EEZ

In this section I model the delineation of the EEZ as a continuous choice. Previous models of "straddling stocks" lack this feature. For example, McKelvey, Sandal, and Steinshamn (2002) assume that there exists a single fish population without spatial dimension. The stock's location alternates from being inside a country's EEZ in one period to being outside the EEZ in the next period. When the stock is inside the EEZ it is harvested by the coastal state; when it is in the high seas it is harvested by a distant water state. A change in the extent of the EEZ would make no difference

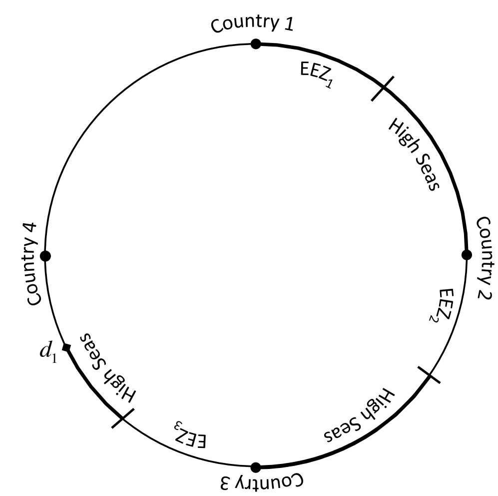
[20] Only for $n = 5$ does a non-signatory to the self-enforcing agreement get a higher payoff compared with the renegotiation-proof agreement. However, if it were not known in advance which country would be in this privileged situation, in expectation, even for this special situation, all countries would choose to negotiate a full-participation agreement.

[21] Two other tuna agreements (the Inter-American Tropical Tuna Commission with 15 members and the Commission for the Conservation of Southern Bluefin Tuna or with eight members) require that decisions be made by consensus or unanimity—rules that effectively give each member a veto. The other tuna agreement (the Western and Central Pacific Fisheries Commission with 25 members) applies a more complicated rule, requiring a three-fourths majority of two sub-groups without any country having a veto.

under this arrangement (unless it gave the stock to one state or the other). In my model, by contrast, an increase in one country's EEZ may benefit this country at the expense of all the others.

As shown in Figure 4, establishment of a uniform EEZ removes segments of the circle that can be fished by every country. This, of course, is the purpose of an EEZ: exclusion. Under customary international law, foreign vessels are permitted to travel through a coastal country's EEZ (innocent passage) but can be barred from fishing in these waters.[22]

Figure 4
Country 1 fishes throughout its own EEZ and in the high seas to distance d_1



Anticipating a symmetric equilibrium, let z denote the length of each country's EEZ and m the number of foreign EEZs from which each country i's fleet is excluded because of i's choice to fish to a distance d_i. In Figure 4, for example, country 1 fishes to a distance d_1, and so is excluded from the EEZs of countries 2 and 3 (but not from

[22] Of course, foreign fleets may be allowed to fish within the EEZ of a third party, but only by means of access agreements. I assume that the coastal state is able to appropriate all of the rents from its property right.

the EEZ of country 4, because d_1 does not extend beyond country 4's home port). In this example, m = 2.

Equations (2.1) and (2.3) now become[23]

$$h_i = \frac{\alpha E_i \left(d_i - zm\right) x}{L} \tag{6.1}$$

and

$$x = K\left(1 - \frac{\alpha}{rL}\sum_i E_i\left(d_i - zm\right)\right). \tag{6.2}$$

We know from before that as z approaches 0, d_i^* will equal L. We also know that as z gets close to L/n, d_i^* will equal L/n. Hence, there must exist a critical value for z such that for z greater than this critical value each country will fish only within its own line segment, and for z less than this critical value each country will fish throughout the ocean. That is, in equilibrium we will have either $m^* = 0$ or $m^* = n - 1$.

Suppose to begin that every country i fishes only within its own line segment (that is, $m = 0$). In a Nash equilibrium, effort will then be given by

$$E_i^*\left(d_i = L/n\right) = \frac{rn\phi}{\alpha\left(n+1\right)}, \tag{6.3}$$

where

$$\phi \equiv \left[1 - \frac{\left(cn + \gamma L\right)}{p\alpha K}\right]. \tag{6.4}$$

[23] I am assuming here that every country i regulates total effort without regard to whether this effort is deployed within its EEZ or on the high seas.

Assume $\phi > 0.$ Substituting then gives

$$\Pi_i^*\left(d_i = L/n\right) = \frac{prK\phi^2}{\left(n+1\right)^2}. \tag{6.5}$$

Suppose instead that every country *i* fishes throughout the ocean, except for the EEZs from which *i* is excluded (that is, $m = n-1$). The Nash equilibrium effort level will then be

$$E_i^*\left(d_i = L\right) = \frac{rL}{\alpha\left(n+1\right)\left[L - z\left(n-1\right)\right]}\left[1 - \frac{L\left(c+\gamma L\right)}{p\alpha K\left[L - z\left(n-1\right)\right]}\right] \tag{6.6}$$

and the Nash equilibrium payoff will be

$$\Pi_i^*\left(d_i = L\right) = \frac{prK}{\left(n+1\right)^2}\left[1 - \frac{L\left(c+\gamma L\right)}{p\alpha K\left[L - z\left(n-1\right)\right]}\right]^2. \tag{6.7}$$

Let

$$\hat{z} = \frac{cL}{cn+\gamma L}. \tag{6.8}$$

By comparing (6.5) and (6.7) we get:

Lemma 1: *If $z < \hat{z}$, coastal states will fish throughout the ocean ($d_i^* = L \forall i$); if $z > \hat{z}$, coastal states will fish only within their own line segment ($d_i^* = L/n$); and if $z = \hat{z}$, coastal states will be indifferent between these extremes.*

When there is no EEZ limit, we know that all coastal states will fish throughout the ocean. Establishment of an EEZ of sufficient size changes this calculus. Traversing an EEZ in order to gain access to the high seas is like paying an entrance fee to fish in these waters. As the EEZ increases, the entrance fee increases and the quantity of fish available in the high seas decreases. Beyond the critical level, $\hat{z}$, it pays each coastal state to fish only within its own line segment.

7. Choosing an EEZ in a closed ocean

How will z_i be chosen? From a game-theoretic perspective, it seems natural to think of the EEZ limit as a Nash equilibrium. In a Nash equilibrium, each country *i* chooses its EEZ value believing that other countries will not change their EEZ limits in response to *i*'s own choice. The Nash assumption of "zero conjectural variations" is compelling from a game-theoretic perspective because in a one-shot model players are *unable* to respond to a change in any country's EEZ.

However, these beliefs are incompatible with the way in which customary law is determined. Though a country can declare any EEZ limit it likes, the claim will only be considered lawful if other states support it, by making the same claim themselves (there are many instances in which a state claimed a right that other states failed to recognize, only to switch to the accepted level once this value had been revealed). As noted in the Introduction, unilateral claims made in the heady 1970s coincided with the Law of the Sea conferences in which proposals for EEZ limits were offered with the understanding that they would apply universally. It is in this context that the 200-mile limit came to be "generally accepted by the international community" (Smith 1986: 30). It thus seems reasonable to assume that each country *i* will choose its own EEZ *believing that every other country will follow suit, choosing the same EEZ*.

Let us then consider both of these assumptions about beliefs, beginning with the Nash assumption. To simplify, assume that if $z = \hat{z}$ then coastal states will fish throughout the ocean. Then, knowing the distances and effort levels that will be chosen subsequently, every country *i* will choose $z_i \in [0, \hat{z}]$ to maximize

$$\Pi_i = \frac{p\alpha K(L - z_{-i})E_i^*}{L}\left\{1 - \frac{\alpha}{rL}\left[(L - z_{-i})E_i^* + \sum_{j \neq i}(L - z_{-j})E_j^*\right]\right\} - (c + \gamma L)E_i^*, \qquad (7.1)$$

where $z_{-i} = \sum_{j \neq i} z_j$ and $z_{-j} = \sum_{v \neq j, v \neq i} z_v + z_i$. Maximization of (7.1) for *i* and of the corresponding payoff functions for every *j*, $j \neq i$, for given property rights arrangements, gives

$$E_i^* = \frac{rL}{\alpha(n+1)\left[L - z(n-1)\right]}\left\{1 - \frac{(c+\gamma L)L\left[L - z_i n + z\right]}{p\alpha K\left[L - z(n-1)\right]\left[L - z(n-2) - z_i\right]}\right\} \qquad (7.2)$$

$$E_j^* = \frac{rL}{\alpha(n+1)\left[L - z(n-2) - z_i\right]}\left\{1 - \frac{(c+\gamma L)L\left[L - zn + z_i\right]}{p\alpha K\left[L - z(n-2) - z_i\right]\left[L - z(n-1)\right]}\right\} \qquad (7.3)$$

where *z* represents the (symmetric) EEZ established by every country other than *i*. Both of these solutions are identical to (6.6) for $z_i = z$.

Substituting these solutions back into (7.1) gives

$$\Pi_i = \frac{pKr}{(n+1)^2}\left\{1 - \frac{(c+\gamma L)L\left[L - z_i n + z\right]}{p\alpha K\left[L - z(n-1)\right]\left[L - z(n-2) - z_i\right]}\right\}^2, \qquad (7.4)$$

which corresponds to (6.7) when *z* is symmetric. Maximizing (7.4) by choice of z_i subject to $z \in [0, \hat{z}]$ requires

$$\frac{2r(n-1)(c+\gamma L)L}{\alpha(n+1)^2}\left\{1-\frac{(c+\gamma L)L\left[L-z_i n+z\right]}{p\alpha K\left[L-z(n-1)\right]\left[L-z(n-2)-z_i\right]}\right\}+\mu-\lambda=0, \tag{7.5}$$

where λ is the Lagrange multiplier on the constraint $z\leq\hat{z}$ and μ is the multiplier on the constraint $z\geq 0$. In a symmetric Nash equilibrium, z_i = z, and the term in brackets in (7.5) will be positive. This means that λ must be positive, which means in turn that the Nash equilibrium is $z^*=\hat{z}$. Finally, since effort and payoffs will be identical for any z larger than this, the Nash equilibrium EEZ is $z^*\in\left[\hat{z},2\pi r_0/n\right]$. The Nash equilibrium effort level is thus given by (6.3) and the payoff by (6.5).

Lemma 2. *In the Nash equilibrium for a closed ocean, all coastal states choose an EEZ that causes all states to fish exclusively within their own line segments, an outcome that is equivalent to complete nationalization of the seas.*

Let us now consider the alternative approach of one-for-one conjectural variations. Substituting the Nash equilibrium values for d_i, E_i, and m_i gives

$$\Pi_i\left(z;z\leq\hat{z}\right)=\frac{rpK}{(n+1)^2}\left[1-\frac{L(c+\gamma L)}{p\alpha K\left[L-z(n-1)\right]}\right]^2, \tag{7.6}$$

and this expression is maximized for $z^*=0$.

For the other situation we have

$$\Pi_i\left(z;z>\hat{z}\right)=\frac{rpK\phi^2}{(n+1)^2}. \tag{7.7}$$

Setting $z^* = 0$ in (7.6) obviously gives (3.9); and, since $\theta > \phi$ for $n > 1$, with one-for-one conjectural variations, countries will want to coordinate on the equilibrium in which $z^* = 0$.

Lemma 3. *In the equilibrium for a closed sea, assuming one-for-one conjectural variations, coastal states will not declare an EEZ of positive length.*

Associating the equilibrium in one-for-one conjectural variations with the value determined by customary law, Lemmas 2 and 3 imply:

Proposition 5. *Customary law, by establishing beliefs that reflect one-for-one conjectural variations, ensures that states do not choose an EEZ of positive value in a closed sea. In doing so, customary law raises payoffs compared to the Nash equilibrium in property rights, but is unable to overcome the tragedy of the commons.*

Under the Nash assumption, every coastal state has an incentive to extend its EEZ so as to exclude others from fishing in its adjacent waters. Just as every state applies too much effort, so every state extends its jurisdiction too far; the Nash equilibrium EEZ is inefficient. When states choose their EEZs in the context of customary law, by contrast, they are unwilling to extend their own EEZs because they do not want other states to extend *their* EEZs. In a closed sea, not having an EEZ is efficient because (recalling Proposition 1) overfishing is caused by excessive effort, not excessive fishing distance.

8. Close the high seas?

Perhaps the most provocative proposal for remedying the tragedy of the commons is to close the high seas to fishing. The Global Oceans Commission (2014) endorsed this proposal (with qualifications), based partly on research by White and Costello (2014); see also Sumaila *et al*. (2015). Currently, negotiations are underway for a new high seas treaty. Complete closure of the high seas is not now on the agenda, but the negotiations are focusing on the establishment of marine protected areas, partly as a means for limiting overfishing, a kind of partial closure.

Like my analysis so far, White and Costello (2014) consider alternative regimes for managing a "closed" ocean (my terminology). Unlike my analysis, however, White and Costello employ a dynamic model in which fishing takes place within "patches" (that is, on points), rather than on a line (their model lacks a "distance" variable), with each coastal state having its own patch and with all states (possibly) having access to an additional patch representing the high seas.[24] Assuming that fishing on the high seas is open to all coastal states (common property), White and Costello find that payoffs are higher relative to the status quo situation when the EEZ is increased so as to "nationalize" the entire ocean. The main reason is their assumption (which contrasts with my own) that fish stocks in the various patches mix incompletely.[25] When the EEZs are extended to eliminate the high seas, each coastal state becomes a "near sole owner" of its "own" stock. This result seems to support Hannesson's (2011) recommendation that the property rights of coastal states should be extended. However it appears from White and Costello's results that extending the EEZs from the current level would sustain rents that are less than half the full potential. An even better outcome, White and Costello show, is to close the high seas and keep the EEZ limit unchanged from its existing level (though the aggregate payoff in this case is still only about 60 percent of the full cooperative level). In their model, closing the high seas helps in two ways. First, as with complete nationalization, closing the high seas forces coastal states to fish only within their own EEZs, where (as explained previously) each state is a "near sole owner." Second, and in contrast to the earlier finding, closing the high seas provides

[24] White and Costello (2014) also consider "open access" in the high seas, which could be interpreted as including distant water states.

[25] To be specific, White and Costello (2014) incorporate a "site fidelity" parameter, S, which equals 0 if the stocks in the various patches mix uniformly (as I assume) and 1 if they do not mix at all. Their main simulations assume $S = 0.75$. Note that site fidelity in this model does not vary with the areal extent of the site.

a source of replenishment for the stocks in each of the EEZs. The high seas, when closed, essentially become a kind of nursery.[26]

What effect would closing the high seas have in my model? Suppose that every country sets a uniform EEZ equal to z'. Taking z' as given, and assuming that a ban on high seas fishing is in place, country *i*'s payoff is

$$\Pi_i^{Ban}\left(z'\right)=\frac{p\alpha Kz'E_i}{L}\left[1-\frac{\alpha z'}{rL}\left(E_i+\sum_{j\neq i}E_j\right)-\frac{\left(c+\gamma z'\right)L}{p\alpha Kz'}\right]. \tag{8.1}$$

Maximization yields

$$E_i^{Ban}\left(z'\right)=\frac{rL}{\alpha z'\left(n+1\right)}\left[1-\frac{\left(c+\gamma z'\right)L}{p\alpha Kz'}\right]. \tag{8.2}$$

Substituting gives

$$\Pi_i^{Ban}\left(z'\right)=\frac{prK}{\left(n+1\right)^2}\left[1-\frac{\left(c+\gamma z'\right)L}{p\alpha Kz'}\right]^2. \tag{8.3}$$

Obviously, this payoff is increasing in z'. Comparing (8.3) to (6.5) and (6.7) we get

Proposition 6. *In a closed sea, payoffs are higher when there is freedom on the high seas and no EEZ than when there exists an EEZ (of any size) and fishing on the high seas is banned. When an EEZ effectively nationalizes the ocean (eliminating the high seas), payoffs are intermediate between these extremes.*

The order of payoffs in my model is the reverse of the order obtained by White and Costello (2014); and the reason, not surprisingly, comes down to our different assumptions. First, in my model, restrictions on distance impose an economic cost,

[26] Obviously, the higher the site fidelity parameter, the lower is this replenishment effect.

whereas in White and Costello's model distance is not a consideration. Second, in White and Costello's model, a ban on high seas fishing partially nationalizes the resource (due to the assumption about site fidelity), limiting the tragedy of the commons, whereas in my model (due to the assumption that the stock is distributed uniformly on the line) closure of the high seas has no such effect. Finally, in my model fish recruitment depends only on the total stock, whereas in White and Costello's model closure of the high seas increases the recruitment of fish from the high seas into the EEZs. Clearly, all of these assumptions deserve careful examination.

9. The Open Ocean

Let us now introduce distant water fishing states. Let there be N such countries, and assume that they have the same payoff functions and the same unfettered access to the ocean as coastal states, being able to set sail from any (or all) of the coastal states' homeports. Without an EEZ, the situations facing coastal and distant water states will be perfectly symmetric, and all of the results obtained previously will go through, only with n being increased to $n + N$. With an EEZ, however, the situations facing coastal and distant water states will be asymmetric. Coastal states, as before, will fish either throughout the ocean or exclusively within their own ocean segment. Distant water states, by contrast, will fish either everywhere in the ocean (that is, along all line segments to which they are given access) or nowhere in the ocean.[27]

Consider first the situation in which all countries fish everywhere except within the EEZs of foreign states. In this case, every coastal state i will choose its effort level to maximize

[27] Of course, what I mean is that the *rents* to fishing would belong to the coastal states. Distant water states may participate in the fishery, but they would have to pay coastal states for the privilege.

$$\Pi_i = \frac{p\alpha KE_i\left[L-z(n-1)\right]}{L}\times \left\{1-\frac{\alpha}{rL}\left[\left(E_i+\sum_{j\neq i}^{n}E_j\right)\left[L-z(n-1)\right]+NE^{DW}\left(L-zn\right)\right]\right\}-\left(c+\gamma L\right)E_i, \quad (9.1)$$

where the superscript *DW* denotes a distant water state. Similarly, every distant water state *i* will choose its effort level to maximize

$$\Pi_i^{DW} = \frac{p\alpha KE_i^{DW}\left(L-zn\right)}{L}\times \left\{1-\frac{\alpha}{rL}\left[\left(E_i^{DW}+\sum_{j\neq i}^{N}E_j^{DW}\right)\left(L-zn\right)+nE\left[L-z(n-1)\right]\right]\right\}-\left(c+\gamma L\right)E_i^{DW}. \quad (9.2)$$

Maximization of (9.1) and (9.2) gives the following Nash equilibrium effort levels:

$$E = \frac{rL}{\alpha(n+N+1)\left[L-z(n-1)\right]}\left\{1-\frac{L(c+\gamma L)\left[L-z(n+N)\right]}{p\alpha K\left[L-z(n-1)\right]\left(L-zn\right)}\right\} \quad (9.3)$$

$$E^{DW} = \frac{rL}{\alpha(n+N+1)\left(L-zn\right)}\left\{1-\frac{L(c+\gamma L)\left(L+z\right)}{p\alpha K\left[L-z(n-1)\right]\left(L-zn\right)}\right\}. \quad (9.4)$$

Now consider the situation in which z is chosen to deter distant water states from fishing in this ocean.[28] Given the assumed symmetry in payoffs, this value of z will also cause coastal states to fish only within their own line segments. Note that this critical value for z will differ from $\hat{z}$, the value that ensures that coastal states earn a higher payoff when fishing only within their own line segments rather than

[28] Of course, distant water states could still fish in this ocean, but only by negotiating access agreements with the coastal states. I am implicitly assuming that the coastal states hold all of the bargaining power in such negotiations.

throughout the ocean. Here, the critical value is calculated to make fishing within any "foreign" country's line segment *unprofitable*.

When coastal states adopt the effort level given by equation (6.3), distant water states will not enter the fishery so long as

$$\Pi_i^{DW} = \frac{p\alpha K E_i^{DW}\left(L-zn\right)}{L}\times \left\{1-\frac{\alpha}{rL}\left[\left(E_i^{DW}+\sum_{j\neq i}^{N}E_j^{DW}\right)\left(L-zn\right)+\frac{Lrn\phi}{\alpha\left(n+1\right)}\right]\right\}-\left(c+\gamma L\right)E_i^{DW} \tag{9.5}$$

is maximized, subject to $E_i^{DW}\geq 0$, by choosing $E_i^{DW} = 0\forall i$.

Let

$$\tilde{z}=\frac{L}{n}\times\left[\theta-\frac{n\phi}{\left(n+1\right)}\right]\Big/\left[1-\frac{n\phi}{\left(n+1\right)}\right] \tag{9.6}$$

denote the critical value that makes fishing by distant water states unprofitable. By our assumptions, the two terms in brackets in (9.6) are positive, and the denominator is larger than the numerator. This gives:

Lemma 4: *If $z<\tilde{z}$, distant water states will fish throughout the high seas $\left(d_i^{DW*}=L\forall i\right)$, whereas if $z>\tilde{z}$, distant water states will exit the fishery $\left(d_i^{DW*}=0\right)$. (If $z=\tilde{z}$, every distant water state will be indifferent between these extremes.)*

As the economics of fishing beyond a coastal state's own line segment is the same for coastal states as for distant water states, we also have:

Lemma 5. *Choice of* $z \in [\tilde{z},\ L/n]$ *ensures that fishing will be done only by coastal states fishing within their own line segments.*

10. Property rights in an open ocean

Which countries get to choose the EEZ, the coastal states alone or the coastal and distant water states together? If both types of country could choose, there will be situations in which coastal states would want to establish an EEZ in "their" ocean but the distant water states would oppose this move. However, the major distant water fishing nations are coastal states in *their* oceans, and customary law applies universally, meaning that EEZs must either be established in every ocean or in no ocean.[29] Rather than model decision making for a multiple of oceans, here, for simplicity, I assume that the decision to establish an EEZ is made solely by coastal states in the ocean under consideration.

Will coastal states be better off restricting access to distant water states by choosing $z \in [\tilde{z},\ L/n]$ or will they be better off sharing the ocean? If they choose z to accommodate entry by distant water states, coastal state i will earn

$$\Pi_i = \frac{pKr}{(n+N+1)^2}\left[1 - \frac{L(c+\gamma L)\left[L - z(n+N)\right]}{p\alpha K\left[L - z(n-1)\right](L - zn)}\right]^2. \tag{10.1}$$

(Eq. (10.1) reduces to (7.6) for $N = 0$.) Maximizing (10.1) by choice of z yields a quadratic equation with one positive solution less than L/n. However, for values of

[29] In the Law of the Sea negotiations, the United States maintained that highly migratory species such as tuna should be exempted from coastal states' control within an EEZ, a claim that was in the United States' self interests, as US tuna fleets mainly fish in the Eastern Tropical Pacific Ocean, outside of the United States' own EEZ. Coastal states in these oceans, naturally enough, refused to recognize the US claim to "their" tuna, sparking a "tuna war" (Rasmussen 1981). The United States later changed its position, at least in the case of the Pacific, when it signed the Treaty on Fisheries between the Governments of Certain Pacific Island States and the Government of the United States of America in 1987; see Munro (1990).

z below this value, reductions in z cause payoffs to rise. Hence, if it pays coastal states to allow fishing by distant water states, coastal states will set z = 0. This is intuitive, for in a closed sea we know that coastal states can't do better than to set z = 0. In this case, the coastal state i will earn the payoff

$$\Pi_i\left(z=0\right)=\frac{pKr}{\left(n+N+1\right)^2}\left[1-\frac{\left(c+\gamma L\right)}{p\alpha K}\right]^2. \tag{10.2}$$

If coastal states choose z so as to make fishing within their own line segments unprofitable for other states, each coastal state i will earn

$$\Pi_i\left(z\in\left[\tilde{z},\ L/n\right]\right)=\frac{pKr}{\left(n+1\right)^2}\left[1-\frac{\left(nc+\gamma L\right)}{p\alpha K}\right]^2. \tag{10.3}$$

It will thus pay coastal states to choose $z\in\left[\tilde{z},\ L/N\right]$ provided payoff (10.3) is at least as large as payoff (10.2). Upon rearranging, and letting $\underline{N}$ denote the minimum number of distant water states needed to make coastal states want to establish an EEZ limit that deters entry by distant water states, we have

$$\underline{N}=c\left(n+1\right)\left(n-1\right)/\phi. \tag{10.4}$$

As discussed previously, choice of an EEZ by coastal states, when this choice is subject to customary law (that is, when choices are made subject to one-for-one conjectural variations), will be efficient from the perspective of the coastal states, giving the result:

Proposition 7. *In an open ocean, an EEZ of value* $z\in\left[\tilde{z},\ L/n\right]$ *will be established in customary law if and only if* $N\geq\underline{N}$; *otherwise, an EEZ of positive value will not be chosen.*

Clearly, an EEZ at least as large as $\tilde{z}$ has the same effect as nationalizing the seas. In a "closed" ocean, such a move is harmful to coastal states; in an "open" ocean, vulnerable to entry by numerous distant water states, coastal states gain by nationalizing the seas. (I have assumed throughout this paper that states regulate their own fleets. With open access to the high seas, nationalization would certainly be in the interests of coastal states.)

Simple theory can thus explain three puzzling features of the property rights regime for the oceans: why it changed in the 1970s (the reason being an actual and/or threatened increase in fishing activity by distant water states), why it "flipped" from zero to a significant positive value rather than increase gradually (the reason being the threshold effect of entry), and why choice of a particular EEZ value was arbitrary (this value needing only to be "large enough" to cause distant water states to exit the fishery).

11. Concluding comments

The international system relies on two main institutions for overcoming the tragedy of the commons in the world's oceans, property rights and cooperative agreements. In the model developed in this paper, both institutions emerge as equilibrium outcomes of the ocean fisheries game. I show that both institutions help to limit overfishing, but that both institutions also fall far short of sustaining a first best outcome when there are a significant number of coastal states. To do better, stronger measures are needed. One proposal is to make participation in a fishery conditional on membership in the relevant RFMO. My analysis suggests that such a move would only shift the burden of enforcement from "unregulated" to "illegal" fishing, having little if any effect on efficiency. The problem isn't that non-compliance would become rampant but that, knowing that compliance will be difficult, countries will weaken the restrictions agreed by a RFMO. Other proposals range from nationalizing the world's oceans to banning fishing on the high seas. My model suggests that these moves would be harmful in a "closed" ocean, with no threat of entry by distant water states. In an "open" ocean, I show that it can pay coastal states to establish an EEZ so as to push distant water states out of the ocean (a move that is equivalent to nationalizing the seas, as under this regime every coastal state fishes only within its own line segment). However, my model predicts that, so long as there are a substantial number of coastal states, pushing out the distant water states will have little effect on efficiency. A change in the property rights regime banning fishing on the high seas would also push out the distant water states, but such a ban would deny coastal states access to the high seas, reducing the efficiency of their fishing activities. Of course, the ban would also do little to reduce overfishing so long as there are a substantial number of coastal states.

Is it possible to do better? It is instructive to consider a rare situation in which a first best outcome was sustained—exploitation of fur seals in the North Pacific (Paterson and Wilen 1977; Barrett 2003). In the late 19th century, the United States claimed an exclusive right to "its" seals (seals that bred on islands belonging to the US) throughout the ocean (at that time, there was no EEZ, only a three-mile territorial limit), but an international tribunal ruled the claim illegal; in the high seas, the tribunal ruled, the seals belonged to every country. Later, a cooperative agreement, the North Pacific Fur Seal Treaty of 1911, effectively restricted access to the seals to just four countries (Canada, Japan, Russia, and the United States) by banning trade in sealskins between parties and non-parties. This outcome was only possible because all of these sealskins were processed in London, and Great Britain represented Canada in the negotiations. Having restricted access to just four countries, the agreement was able to sustain full cooperation—an outcome that is consistent with the theory presented in this paper.[30] However, since the conditions

[30] The agreement was able to sustain a first best outcome not only by limiting membership to four countries, but also by banning the killing of seals at sea (a policy akin to a ban on high seas fishing). The ban transformed what had been a common property resource into one exploited by three different sole owners, as three of the four parties (Japan, Russia, and the United States) had their own breeding populations (the reason for Canada's participation is explained in the next paragraph in the text). Though territorial restrictions on fishing at sea are costly in the model developed in this paper, for the fur seals the reverse was true; it was far more efficient to kill the seals on land than at sea.

that allowed the Fur Seal Treaty to be effective don't apply to highly migratory fisheries (fish like tuna can be processed anywhere), this example proves the rule that our existing institutions are unable to overcome the tragedy of the commons on the world's oceans. [31]

Another feature of this agreement *appears* relevant to highly migratory stocks. Canada, which lacked a fur seal breeding population, agreed to stop sealing on the high seas altogether on the condition that it get a share of the harvests taken by the three parties with breeding populations. This suggests that the way to manage the world's ocean fisheries is to limit the right to harvest to four or fewer countries, and for these countries to share the rents from this arrangement with the excluded countries. However, the model developed here shows why this approach won't work. Even if a fishery were exploited by just five countries, four of which cooperated by international agreement, the fifth country would be better off free riding than by joining the agreement and sharing the gains to full cooperation equally with the other four countries.[32]

Gordon Munro (2007) has suggested not only that the right to fish should be conditional on membership in the relevant RFMO but that RFMOs should have the right to restrict membership. In particular, he says that the right to fish should be limited to an agreement's "charter" members (in the parlance of the Law of the Sea, states having a "real interest" in the fishery). My model, however, suggests that this approach would only make a difference if the number of countries having a "real

[31] Gordon Munro told me of another success, collective management of the Norwegian Spring Spawning herring. Because of this species' spawning and migration patterns, Norway plays a dominant role in the fishery, which is exploited by only four other states (Russia, Iceland, the European Union, and the Faroe Islands, which is represented by Denmark, an EU member). Here, the EEZ limits access to the coastal states, as "[i]t is questionable whether it would be economically feasible for prospective new member vessels to operate in the herring fishery, unless they were granted access to the EEZs of the five" (Bjørndal and Munro 2012: 256). Because the number of coastal states is small (no more than five and arguably only four, given Denmark's membership in the EU), my model predicts that management of this fishery should be approximately efficient.

[32] It might seem that the use of side payments can avoid this problem, but Carraro and Siniscalco (1993) show that side payments only help if the players can make commitments, such as a commitment by pre-existing parties to remain in the agreement, and sovereignty precludes such behavior.

interest" in a fishery were very small. As it would be impractical to deny coastal states access to their adjoining ocean, this approach, like the others discussed in this paper, would do little to reduce overfishing in oceans having more than a handful of coastal states.[33]

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[33] Only one tuna agreement restricts membership in the RFMO—the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. This agreement limits participation to 25 named states (all the coastal states plus all the distant water states with a history of fishing in this ocean) but allows more states to be admitted by a consensus of the existing parties (Indonesia was admitted in 2013, making membership 26). This agreement is able to restrict membership because fishing in the high seas areas of this ocean are only economic if a state is also given access to the surrounding EEZs.

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