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Abstract

I model the ocean as an array of lines set within a two-dimensional frame, and show how the Exclusive Economic Zone emerged as an equilibrium in customary international law. I find that custom codifies the efficient Nash equilibrium of enclosure for nearshore fisheries. For highly migratory and offshore fisheries, enclosure is inefficient, and customary law supports a more efficient "free sea" regime. The model also identifies the trigger for changes in property rights and the reason choice of a particular limit, like the current 200-mile zone, is arbitrary. In an asymmetric, regional sea, I find that the scope of the EEZ is determined by the relative power of coastal and distant water states, and need not be efficient. Finally, I find that proposals to nationalize the seas or ban fishing on the high seas are neither efficient nor supportable as equilibria in customary law.

JEL-Codes: K330, F550, Q220.

Keywords: customary international law, exclusive economic zone, ocean fisheries, closure of high seas.

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1. Introduction

Collective action at the international level is aided by two kinds of institution, customary international law and treaties. Custom determines the rules of the game; treaties address specific issues. Custom applies universally; treaties apply only to the countries that consent to be bound by them. Custom emerges spontaneously; treaties are constructed deliberately. Custom changes rarely; treaties are negotiated and renegotiated all the time. A substantial literature has modeled treaties as devices for achieving collective action, implicitly taking customary law as given.[1] By contrast, though a few papers have used game theory to interpret custom, the question of how to model this institution remains unsettled. In this paper I model an important and unusually clear example of customary law: creation of a new kind of property right to the world's ocean fisheries, the exclusive economic zone.[2]

The world's EEZs, shown in Figure 1, make up about 40 percent of the world's ocean and almost 30 percent of the Earth's surface. When first established, about 99 percent of the world's commercial catch was taken within these zones (today, about 97 percent).[3] Creation of the EEZ marks one of the most significant developments in the history of property rights, and yet the origins and consequences of this event have been largely neglected by economists. How and why did the EEZ come to be adopted? Why was it set at 200 nautical miles rather than some other value? Do EEZs increase rents or merely redistribute them? Recently, more radical changes in property rights have been proposed as a (partial) remedy to persistent overfishing, from complete

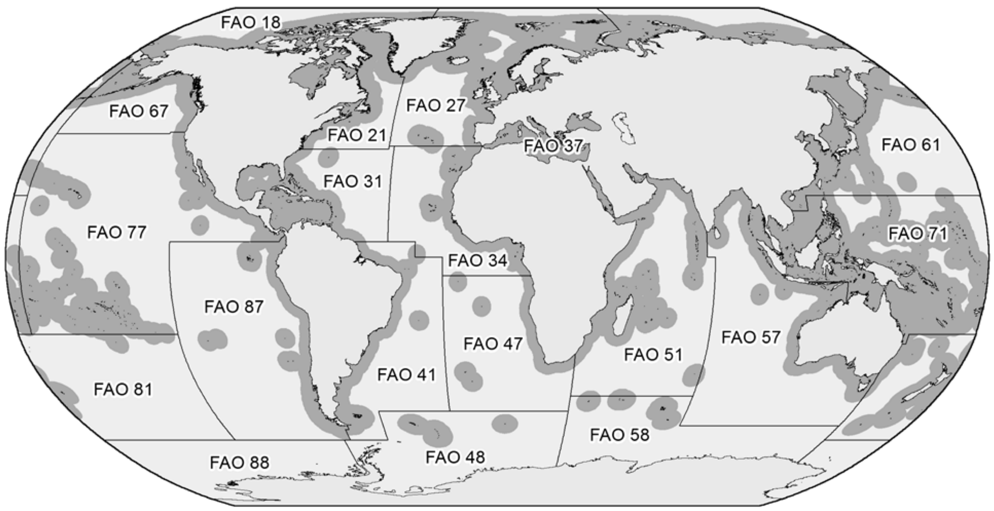
[1] For example, the literature on international environmental agreements implicitly assumes (see Barrett 2003) that compliance is given—an assumption that is consistent with the customary principle known as *pacta sunt servanda* (treaties are to be kept).

[2] Coastal states have exclusive rights to all living resources found in the water column inside their EEZs, whereas in the high seas, all states are free to fish. Coastal states also have rights to the resources of the seabed and subsoil (including oil, gas, and minerals) of the continental shelf, the submerged portion of a continent's land mass. These rights apply automatically up to 200 miles from shore, and may extend up to 350 miles, or 100 miles from the 2,500-meter isobath, whichever is greater, where the continental shelf extends beyond the 200-mile limit.

[3] http://www.seaaroundus.org.

nationalization of the ocean to a ban on high seas fishing.[4] Could these proposals be supported as equilibria of the ocean property rights game? Would rents increase if they were? In this paper I develop a model capable of answering these questions.

Figure 1. Exclusive Economic Zones



Source: http://www.seaaroundus.org/catch-reconstruction-and-allocation-methods/

The model incorporates two novel features: (i) a geography of the ocean, its fisheries, and the economics of their exploitation; and (ii) the institutional setting in which property rights to the ocean come to be established.

I take the original, static representation of the fishery developed by Gordon (1954), which the literature subsequently developed in a dynamic direction (beginning with Scott 1955), and set it in a spatial context. Most dynamic fisheries models have zero spatial dimension, and thus ignore the aspect of a fishery that is critical for understanding the emergence and evolution of property rights. For simplicity, I ignore dynamics (stocks in my model should be interpreted as steady state values), and model the ocean as an array of lines, each of one dimension, situated in a circle, a two-dimensional plane. Coastal states are assumed to be symmetric, and represented

[4] Englander (2019) shows that unauthorized fishing is substantially lower just inside the EEZ than just outside, implying that EEZs are enforced and thus of value to the states that claim them.

by homeports (points) spaced equidistantly around the circle. I model three types of fishery—nearshore, offshore, and highly migratory—and assume that their stocks are distributed uniformly on the line or lines corresponding to their range. States choose fishing effort (fleet size), as usual, and distance, a new variable. Fishing a greater distance is more costly, but provides access to a larger share of a given stock.

I first solve the model taking the EEZ as given. It might be zero, implying freedom throughout the seas, the historical situation, or positive, as it is today. Finally, I let coastal states *choose* this property right. If states choose a value of zero, the equilibrium is freedom throughout the seas. If they choose a positive value, the equilibrium is an EEZ, possibly coupled with a high seas area.

Property rights to the ocean are not determined by individual choice alone. They are established in customary law. Defining an equilibrium in customary law is the second critical feature of my model. A customary law exists if states behave in accordance with the law, and do so in the belief that they *are legally obligated to behave in this way* (Bodansky 1995). Because custom is partly founded in beliefs, lawyers have debated whether it truly exists let alone whether it has real effects. Most importantly, Goldsmith and Posner (1999) argue that behaviors consistent with self-interest have been misinterpreted as customary law. They also argue that custom is incapable of solving multilateral collective action problems.[5] Here I model choice of an EEZ as determined by countries acting independently and in their national self-interests (Nash behavior), and by countries acting independently and in their national self-interests but with the understanding that any country's claim to an EEZ will only be considered lawful if others assert the same claim (customary law). By distinguishing between these equilibria, I am able to show whether customary law exists independently of Nash behavior and has real effects.

[5] Norman and Trachtman (2005), by contrast, argue that customary law sustains efficient equilibria in a repeated prisoners' dilemma. The difficulty with this approach is distinguishing behavior supported by custom from behavior that could also be supported by non-cooperative behavior.

Consistent with Goldsmith and Posner (1999), I find that, in some situations, custom and Nash behavior coincide. However, in other situations, custom supports an equilibrium that is very different from, and preferred by all countries to, the Nash equilibrium. This is for a symmetric ocean. In a regional sea in which coastal and distant water states vie to define the EEZ's scope, I find that the interpretation that wins out is determined by the relative power of these antagonists and need not be efficient. My model thus offers both a sharper and a more complex reading of customary law than the previous literature.

A theory of property rights to the ocean must not only explain why the EEZ emerged when it did, but why a regime of freedom of the seas prevailed previously. My model shows that, were it not for customary law, countries would have nationalized the seas. The regime of freedom of the seas thus reflects the restraining influence of custom.

Why did freedom of the seas give way to a 200-mile EEZ? Why was the change adopted in one fell swoop rather than incrementally? Verdier and Voeten (2014) argue that customary law "tips" due to heterogeneous preferences. In my model, by contrast, custom changes discontinuously as the value of an exogenous variable crosses a critical threshold. Below the threshold, one property rights regime is adopted (freedom of the seas); above it, another is adopted (the EEZ). The variable that causes this shift is entry by foreign fleets.

Another fascinating feature of the EEZ is that its precise value, 200 miles, finds no justification in ecology, economics, or legal precedent. In my model, the equilibrium EEZ established in customary law is either zero or a strictly positive value that is bounded but indeterminate. The value selected to satisfy this requirement comes from outside the model and is chosen for its "focal" qualities (Schelling 1960).

Customary law also underpins choice of effort, a variable that has always been central to fisheries economics, and distance, a new variable that only surfaces as being important when the ocean is of positive spatial dimension. The custom of "freedom of fishing” allows countries to apply effort as they please. The custom of “freedom of navigation” allows fishing vessels to travel throughout the seas. I find that freedom of navigation is efficient but that the freedom to fish leads to inefficiency.

Why not limit the freedom to fish in customary law? Optimal effort is stock-specific and depends on ecological, technological, and economic conditions that vary over time. It cannot be reduced to a simple, universal rule. Instead, states try to choose their effort levels cooperatively through regional fisheries management organizations. As RFMO performance has generally been disappointing, and also to simplify, in this paper I take it that states choose their effort levels freely.

In addition to explaining the past, my model can be used to evaluate proposals to change today’s regime. One radical suggestion is to extend the EEZ so as to eliminate the high seas entirely (Hannesson 2011). As explained before, I find that this is the inefficient Nash solution. Full nationalization of the ocean would end free access by distant water states, but it would also limit access by neighboring coastal states and, depending on the spatial distribution of the fishery, have no effect on their incentive to overfish. Another radical proposal is to retain the current EEZ but ban fishing on the high seas (Global Ocean Commission 2014). In contrast to White and Costello (2014), I find that that such a ban is the worst of all property rights remedies. Like the other proposal, it fails to limit overfishing by coastal states. In addition, by imposing a tougher restriction on where these states may fish, it increases costs. I find that neither proposal can be supported as an equilibrium in customary law.

The sections that follow: provide a brief history of property rights to the ocean; present the model; solve for effort and distance assuming a given EEZ; derive property rights equilibria in customary law and compare these to their Nash counterparts; examine how coastal and distant water states compete to establish property rights in a regional sea; and evaluate the proposal to close the high seas. The final section summarizes the main results and suggests directions for further study.

2. Emergence of a New Property Right

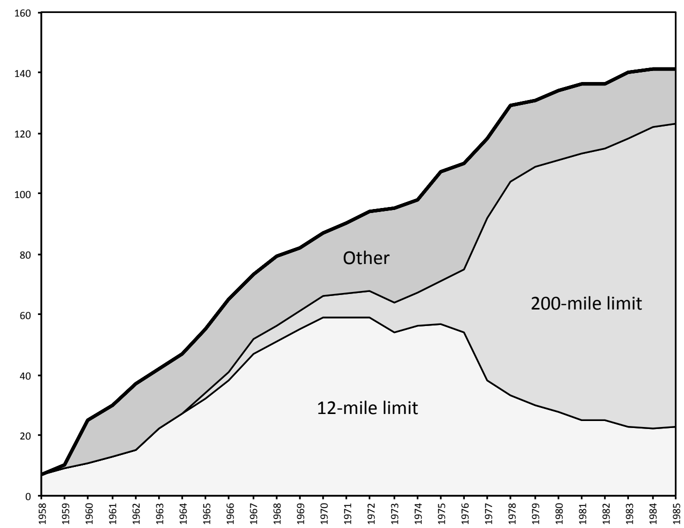
The EEZ emerged out of a process whereby a coastal state would assert an exclusive right to fish beyond its traditional, three-mile territorial sea, and other states would respond either by asserting the same right, by acquiescing to it, or by denouncing it. Contemporaneous with these developments, property rights to the ocean were being discussed in a series of Law of the Sea conferences. These were complementary processes. Unilateral claims revealed dissatisfaction with the *status quo ante*. The conferences coordinated choice of a new rule and facilitated negotiation of a grander bargain over related issues, such as the delineation of the territorial sea and access to resources on and beneath the continental shelf and deep seabed. Though the 200-mile limit is codified in the Law of the Sea treaty, adopted in 1982, "[i]t is at the very least arguable that [the EEZ was] established… in general customary law *before* [my emphasis] it was adopted in the final Convention text" (Lowe 2013: 204). By the nature of customary law, we can't pinpoint a precise date by which the EEZ became established. However, a milestone for its acceptance was the United States' claim to a 200-mile conservation zone in 1976, upgraded to a 200-mile EEZ in 1983—a claim that endures despite a failure by the US to ratify the Law of the Sea Convention.

Figure 2 shows the number of fisheries-related claims made over time, divided into three categories—12-miles, 200-miles, and "other."[6] As the aggregate of these claims (shown by the dark line) is increasing, the figure reveals a growing desire for change. At the first Law of the Sea Conference in 1958, a number of countries proposed a 12-mile exclusive fisheries zone. Over time, support for a 12-mile limit increased; by 1972 it looked as if a 12-mile limit might become law. By 1979, however, backing for the 12-mile limit had eroded, whereas support for a 200-mile limit had grown ten-fold (the US declared a 12-mile exclusive fishing zone in 1966 but changed this to a 200-mile zone in 1976). In just a few years, property rights to the world's oceans had

[6] The figure reports the most extensive claim to a fisheries zone by each state. For example, if a state claimed both a 12-mile territorial sea and 200-mile EEZ, the figure shows only the latter limit.

flipped. At the start of the decade, a three-mile territorial limit prevailed; by the end, a 12-mile territorial sea coupled with a 200-mile EEZ had taken its place.

Figure 2. Claims to a 200-Mile Exclusive Economic Zone



Source: Compiled using data from Smith (1986).

It might appear from Figure 2 that support for the 200-mile limit was less than universal well into the 1980s, as some states continued to claim 12-miles and others a different value altogether. However, custom doesn't *require* that coastal states claim an EEZ; it merely *permit*s them to do so. States claiming a 12-mile zone at this time were really claiming a 12-mile territorial limit and *no* EEZ. Why would a state not claim an EEZ? In the semi-enclosed Mediterranean, the reason was the fear that other states would make a reciprocal claim, forcing each to fish only within its own EEZ. This explains why France and Spain declared an EEZ on their Atlantic coasts but not, until recently, in the Mediterranean.[7] Even now, only five out of 18 Mediterranean states have declared an EEZ in this sea. Finally, the reason so many claims fall in the "other" category is due to geography.[8] For example, the sea separating Sweden from its neighbors is less than 400 miles in every direction, constraining Sweden to an EEZ

[7] France proclaimed a Mediterranean EEZ in 2012. Spain initially protested against this move, but then reversed its position, declaring its own Mediterranean EEZ in 2013.
[8] Under the Law of the Sea Convention, archipelagic states may claim an EEZ greater than 200-miles, subject to certain restrictions, where the distance separating their islands exceeds this amount.

of less than 200 miles. In sum, by the late-1970s, states claimed a 200-mile EEZ when doing so was feasible and desirable, a shorter EEZ when an EEZ was desirable but a 200-mile limit infeasible, and no EEZ when an EEZ was undesirable.

Though Figure 2 ends in 1985, the situation today is little changed. Of the 149 member-states of the United Nations with a coastline, 113 have declared a 200-mile EEZ, 21 a 12-mile territorial sea and no EEZ, and 15 an EEZ of between 12 and 200 miles for reasons of geography.[9] The 200-mile limit established in the mid-to-late-1970s remains the customary rule today.

Why did freedom of the seas prevail previously? A different regime could have been chosen. Indeed, centuries ago, a different regime *was* chosen. The 1494 Treaty of Tordesillas divided the world along a meridian 370 leagues west of the Cape Verde Islands, assigning the eastern half to Portugal and the western half to Spain. It was not until the early seventeenth century that the principle of *mare clausum* (closed sea) came to be challenged by its opposite, *mare liberum* (free sea), and not until the late eighteenth century that the cannon-shot rule, which later became the three-mile territorial sea, predominated. In my model, the Nash equilibrium sustains a closed sea regime of the type claimed by Portugal and Spain, and custom either a free sea regime (no EEZ) or an EEZ coupled with a free high-seas (the current situation).

The process of establishing an EEZ began with a proclamation issued by President Harry S. Truman on September 28th, 1945. This asserted the right of the US to establish fisheries conservation zones "in those areas of the high seas contiguous to [its] coasts," due to a concern about "the inadequacy of present arrangements for the protection and perpetuation of the fishery resources" in these seas.[10] Critically, Truman went on to acknowledge the "right of *any* [my emphasis] State to establish

[9] In 1985, there were 159 UN members. Today, there are 193. Data for the current status of maritime claims are from https://www.cia.gov/library/publications/the-world-factbook/fields/283.html.
[10] On the same day, Truman issued another proclamation on the natural resources of the subsoil and seabed of the continental shelf, sparking an international process for defining the continental shelf and for determining property rights in relation to it, which, like the EEZ, are established in customary law.

conservation zones off its shores in accordance with" the same principles, virtually announcing that his claim, to be legitimate, had to be accepted in customary law.

Inexplicably, having stirred the pot, the US failed to make a specific claim. Chile became the first country to do this, declaring 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 moved next, wanting also "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). Later, all three consolidated their claims in the Santiago Declaration of 1952, but their movement ended there. No other country joined them, and the US opposed their claims. At that time, claims to a 200-mile zone were just claims, not law.

Inspired by these early moves, however, Iceland declared a four-mile fishery limit in 1952, followed by a 12-mile limit in 1958 and a 50-mile limit in 1972. The United Kingdom, which had fished in these waters for centuries, protested, but because the disputes between these countries were resolved through bilateral agreements, Iceland's claims failed to presage a change in custom. Beginning in 1972, however, the old regime showed signs of crumbling. Kenya introduced draft articles on the concept of an "Exclusive Economic Zone" to the UN Committee on the Seabed, and more and more countries began asserting a 200-mile limit. By the time Iceland did so in 1975, provoking a third Cod War with the United Kingdom, customary law seemed ready to tip. The final blow came in 1976, when countries attending the fourth session of the Third Law of the Sea Conference recognized the right of coastal states to establish an EEZ. Indeed, even the United Kingdom, which had strongly opposed Iceland's 200-mile claim, extended its own Exclusive Fisheries Zone to 200 miles in 1977.[11] Within a year or two, property rights to the world's oceans had undergone an unprecedented regime change.

[11] The United Kingdom established an Exclusive Economic Zone in law only in 2013.

Why 200 miles? The choice can be traced to Chile's initial claim, which later became a focal point. But why did *Chile* choose 200 miles? It turns out that, for Chile's purposes, "the distance finally adopted could as easily have been 50 or 300 miles as 200 miles" (Hollick 1977: 495). The idea of declaring a limit originated with a Chilean whaling company, which had hoped to prevent distant water fleets from returning to the seas near Chile after the end of World War II. The company only wanted a 50-mile zone, but its legal counsel said that the value it proposed value had to be grounded in legal precedent. The precedent they identified was the 1939 Declaration of Panama, an agreement that had nothing to do with fishing but that aimed to keep the waters off of the Americas "free from the commission of hostile acts" during World War II. Why did the *Declaration* choose 200-miles? It turns out that it didn't. The US Department of State favored a 300-mile zone, and prepared a map showing these contours. Upon seeing it, President Franklin D. Roosevelt took out a pencil and added eleven small "x" marks to the zone's outer boundaries, and then drew "straight lines with a ruler between those points."[12] This widened the breadth of the security zone to 300-500 miles (Armanet 1984: 29). Though Roosevelt's proposal was adopted in Panama, the final declaration identified his eleven points only by their coordinates. In another turn, the whaling company ignored these and instead relied on a map of the deal that appeared in a Chilean publication. However, this map mistakenly showed the security zone extending only 200 miles from Chile's coast, and Chile's President, Gabriel González Videla, accepted this value without fact-checking (Armanet 1984: 29). The 200-mile value was thus essentially plucked out of thin air. It had no logical basis. Consistent with my theory, however, it sufficed for a universal EEZ because a "correct" value neither existed nor was needed.

Finally, what explains the *timing* of the EEZ's creation? Technical progress probably played a role. As noted by Valdemarsen (2001: 636), "in the 1960s and early 1970s powerful new fleets were built which could operate far from the base, using highly

[12] See https://history.state.gov/historicaldocuments/frus1939v05/map-panama. The declaration is at https://history.state.gov/historicaldocuments/frus1939v05/d60.

efficient gear such as the pelagic trawl and the purse seine, and in some cases with on board processing of the catch" Another reason is that the number of nation states, as measured by membership in the United Nations, tripled from 1945 to 1978, mainly due to de-colonization. Moreover, the new states had no fealty to the pre-existing ocean regime. Instead, they sought to transform "the world system into one governed under a 'New International Economic Order'" (Friedheim 1993: 19).

3. Model

My model is grounded in the classic Gordon-Schaefer description of a fishery (Gordon, 1954; Schaefer, 1954), which the literature subsequently developed in a dynamical direction, beginning with Scott (1955). In this paper, I develop it in a spatial direction.

In the standard model, the fishery inhabits a point. Previous papers modified this model by representing the fishery as a multiple of points or "patches" (Sanchirico and Wilen 1999, 2005), linked by diffusion equations that describe the movement of fish between points. White and Costello (2014) and Finus and Schneider (2015) adapt this approach to ocean fisheries, designating some "patches" as EEZs and a residual one the high seas. However, all of these models lack a true geography. In my model, the fishery is represented by a line, situated a calculable distance from every coastal state.

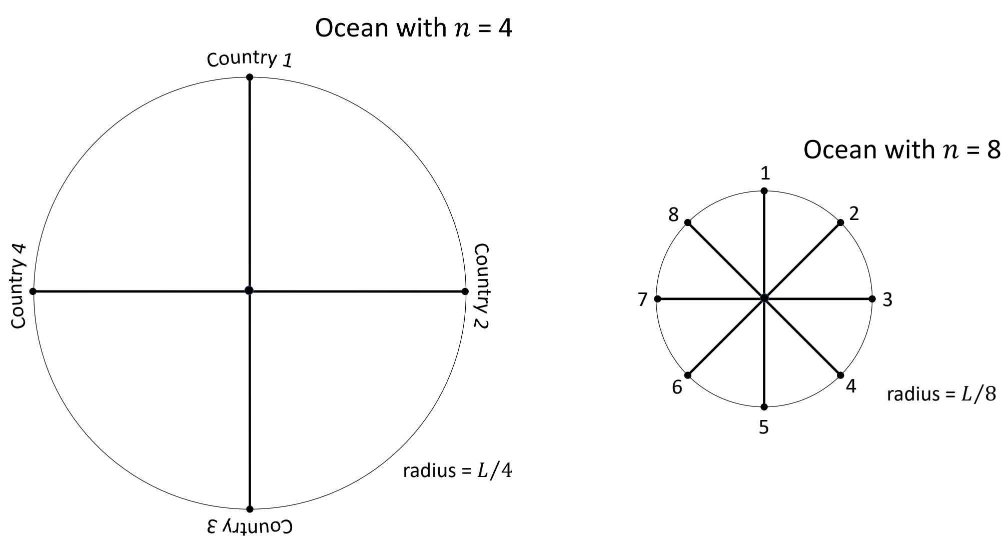
Herrera et al. (2016) also place the fishery on a line, but without reference to the ocean or the players' sovereign territories. In their (dynamic) model, states choose effort along sections of a line, guided by such considerations as where the preponderance of fish are located and their assumption that individual effort is costlier where total effort is greater. They find that states have incentives to forgo fishing within some sections so as to shift stocks to neighboring areas, and that, as the number of countries increases, these "no fish" sections shrink and eventually disappear. Herrera et al. (2016) call these sections "reserves," though they are *de facto* rather than *de jure* reserves. In my paper, property rights are established in law.

As my model is static, stocks are best interpreted as steady state values. Finus and Schneider (2015) also employ a static model. White and Costello (2014) and Herrera et al. (2016) use dynamical models, but their analyses focus on steady state solutions. All of these papers rely on simulations. Here, I derive analytical solutions.

In common with these papers, my model is symmetric (later I consider an important asymmetric situation). The ocean consists of an array of one-dimensional lines, set within the two-dimensional plane of a circle. Each line connects a different country's "homeport" to the center of the circle. As there are n countries, there are n homeports and, thus, n lines. Denoting the total length of the ocean by L, the length of each country's line segment is $l = L/n$. This is a "hub and spoke" ocean.

Figure 3 shows two different configurations, one for $n = 4$ and one for $n = 8$. Though the circle shrinks as n increases, the ocean's size (length) is fixed and equal to the sum of the lengths of the line segments. In any game, n is given, though we may wish to know how the equilibria vary with n. For example, in the years leading up to and overlapping with establishment of the EEZ, 61 coastal states gained their independence, increasing n substantially.

Figure 3. The "Hub and Spoke" Ocean



An important assumption concerns the spatial distribution of a stock in relation to the ocean. I consider three fisheries, illustrated in Fig. 4 assuming n = 4.

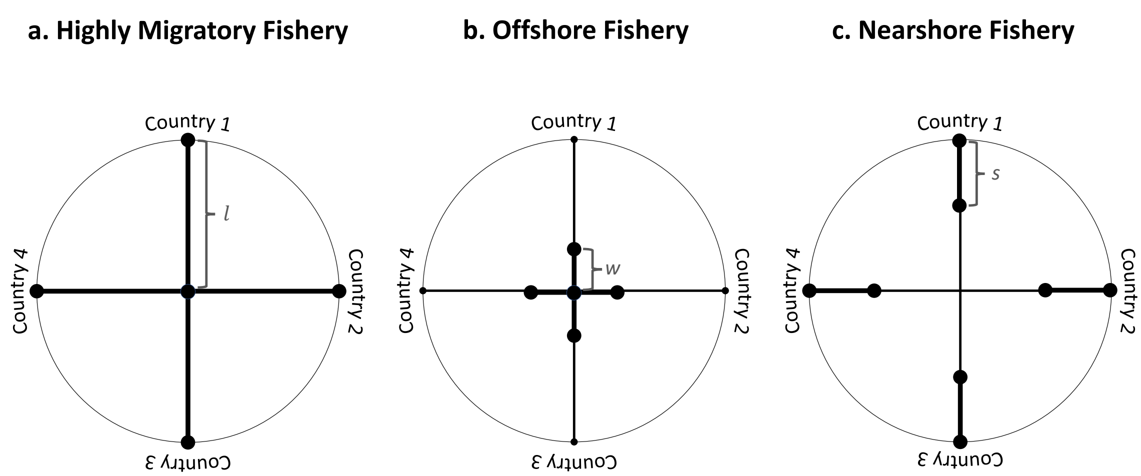
1. A *highly migratory* fishery, distributed uniformly on the ocean of length L; see Fig 4a. The uniformity assumption holds roughly for species like tuna, which are caught both inside and outside today's 200-mile EEZ. Note that this distribution can also be interpreted as representing transboundary stocks shared by a subset of countries in a regional sea (such as anchoveta, shared by Chile and Peru), as n can be any positive integer value. Most harvested species are fished from shared stocks.

2. An *offshore* fishery of length $W, W \in (0, L)$, divided equally among n lines (making the length of the fishery on every line $w = W/n$), each of which radiates out from the center of the circle in the direction of a different homeport; see Fig 4b. Offshore stocks include toothfishes, found in deep waters, the only commercially-important species harvested exclusively in the high seas, and species like cod and halibut, found in relatively shallow, offshore waters. If the EEZ exceeds $l - w$, the offshore stock is a "straddling stock."

3. n biologically independent and spatially separate *nearshore* stocks, distributed uniformly on every spoke, beginning at each state's homeport and extending in the direction of the circle's center to a distance $s, s \in (0, l)$; see Fig 4c. As the total length of ocean populated by nearshore fisheries should be independent of n, denote this length S, making $s = S/n$. Similarly, let K denote total carrying capacity, and $k = K/n$ the carrying capacity of an individual fishery. Nearshore fisheries are normally found between the shore and the limit of the continental shelf, which extends, on average, about 30 nautical miles from shore, but can stretch beyond the current, 200-mile EEZ. This is where the primary producers, plankton, obtain their nutrients due to upwelling,

supporting the world's most productive fishing grounds. Nearshore stocks that protrude from the EEZ are also straddling stocks.

Figure 4. Three Linear Fisheries



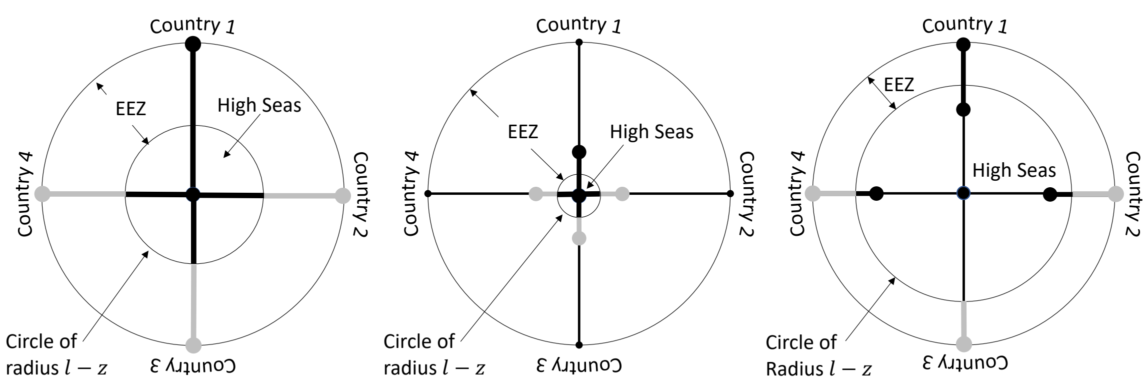
Notice that, as $w \to l$, the distinction between offshore and highly migratory stocks blurs (both comprise a single stock). Though situated differently in the two-dimensional plane, with or without an EEZ, both stocks are the common property of n states. Also, different assumptions could be made about the distribution of fish. The assumption of a uniform distribution is the simplest, but any distribution supported on a bounded interval could be analyzed within the framework of this paper.

A novel choice in this model is the distance a fleet travels from its homeport. A fleet must first travel *to* the fishery. It must then travel a positive distance once *in* the fishery in order to harvest a positive catch. Finally, to sell its catch, it must return to its homeport. Let d_i denote i's chosen *outbound* distance. This determines a state's *access* to a fishery. The roundtrip distance, $2d_i$, determines a state's *cost* of fishing.

Under international law, states may travel throughout the ocean, but their access to a fishery depends on the property rights regime. Assume for now that the EEZ is given and of uniform length. This length, denoted by z, could be zero, as it was before 1970, or positive, as it is today. Figures 4a-c show access to all three fisheries under a *free* sea regime ($z = 0$), and Figures 5a-c show access under a positive EEZ ($z > 0$) regime (again, for n = 4), with the latter being drawn from Country 1's perspective. Establishment of a positive, uniform EEZ allows Country 1 to exclude others from a section of a fishery closest to its homeport, but reduces 1's access to sections closest to other countries.

Figure 5. EEZs in the Three Linear Fisheries

a. Highly Migratory Fishery **b. Offshore Fishery** **c. Nearshore Fishery**



In a highly migratory fishery, choice of any $d_i > 0$ puts i *in* the fishery, giving i access to the stock, denoted by x. (To minimize notation, I use superscripts to denote the type of fishery only when presenting the main results.) By the uniformity assumption, the stock available to i, x_i, is $x_i = xd_i/L$ for $d_i \in [0, l + (n-1)(l-z)]$.

To exploit an offshore fishery, i's fleet must first travel *to* the fishery, a distance $l - w$ from i's homeport ($x_i = 0$ for $d_i \in [0, l-w]$). From there, the stock available to i depends on how far the fleet travels *in* the fishery and on whether the fishery overlaps with the EEZ. If the fishery lies beyond the EEZ ($l - w \geq z$), then $x_i = x(d_i - l + w)/wn$ for $d_i \in [l - w, l + w(n-1)]$. If some portion of the fishery lies inside the EEZ ($l - z \leq w$, as in Fig. 5b), then $x_i = x(d_i - l + w)/wn$ for $d_i \in [l - w, l + (n-1)(l-z)]$.

Finally, as nearshore stocks are assumed to be ecologically independent, I take it that i dispatches a different fleet to every nearshore fishery. Denote the stock adjacent to country i's homeport by x^i. Then the stock available to i in fishery i is $x_i^i = x^i d_i^i / s$ for $d_i^i \in [0, s]$ and $x_i^i = x^i$ for $d_i^i \in [s, l]$. To exploit nearshore fishery j, $j \neq i$, i's fleet must first travel to the center of the circle, and from there along country j's line segment in the direction of j's homeport. Country i is unable to access the stock if either $d_i^j \in [0, 2l - s]$ or $s \leq z$. To gain access the stock, the fishery must extend beyond j's EEZ $(s > z)$ and i must enter the fishery $\left(d_i^j \in [2l - s, 2l - z]\right)$. Upon entering, i gains access to $x_i^j = x^j \left[d_i^j - (2l - s)\right]/s$.

For highly migratory and offshore fisheries, country i's harvest, h_i, is assumed to depend on i's effort, E_i, and the stock available to i. Similarly, for nearshore fishery i, country j's harvest is assumed to depend on the stock of fishery i available to j, and on the effort j allocates to i:[13]

$$h_i = \alpha E_i x_i, \qquad h_j^i = \alpha E_j^i x_j^i. \tag{1}$$

Assuming logistic growth, the aggregate harvest in the highly migratory and offshore fisheries is given by h, and in nearshore fishery i by h^i:

$$h = \sum_{i=1}^{n} h_i = rx\left(1 - \frac{x}{K}\right), \;\; h^i = \sum_{j=1}^{n} h_j^i = rx^i\left(1 - \frac{x^i}{k}\right)\forall i, \tag{2}$$

where r denotes the intrinsic rate of growth of the stock (biology), K and k denote carrying capacity (ecology), and x and x^i are interpreted as steady state values. In the Appendix, I show how these values depend on effort and distance.

[13] To simplify notation, I assume that every stock has the same catchability coefficient, α, and the same parameters r, K, p, c, and γ introduced later in this section.

We must also specify costs. For the highly migratory and offshore fisheries, denote i's costs by C_i; and, for the ith nearshore fishery, denote j's costs by C_j^i:

$$C_i = (c + \gamma d_i)E_i, \qquad C_j^i = \left(c + \gamma d_j^i\right)E_j^i \ \forall i, j; \quad c, \gamma > 0. \tag{3}$$

If distance is given, eqs. (3) reduce to the standard assumption, dating back to Gordon (1954), that costs are proportional to effort (see also Clark 2006). The parameter c represents the cost of boats and crews sitting in their homeport, and γ the per unit cost of fishing to a distance d_i or d_i^j from i's homeport, *inclusive of the return journey*.[14] The novelty in eqs. (3) is the spatial dimension.

The assumption that costs are linear in distance seems a natural companion to the assumption that costs are linear in effort. It might be supposed that marginal distance costs are increasing. However, though costs must be incurred to keep vessels at sea for longer, and to travel greater distances, investments in transshipment and resupply vessels allow owners to avoid "the fuel expenditure and lengthy breaks in fishing required to return to port or their home countries," a cost savings (Tickler *et al*. 2018: 3). Indeed, since 1950, mean distance fished has doubled; today, all parts of the ocean are exploited, except for the polar extremes (Tickler et al. 2018).

According to eq. (1), to obtain a positive harvest, a state must expend a strictly positive effort over a strictly positive distance in a fishery. Increases in effort and distance are equally effective in increasing harvests, but (3) implies that effort is the costlier option. Hence, if a state chooses to operate within a fishery, it will want to fish *everywhere* it can within the fishery.

4. EEZ given

[14] The cost for a one-way journey is thus $\gamma/2$ per unit of distance for given effort.

How will nations exploit these fisheries when the EEZ is given? In a highly migratory fishery, coastal state i's profit from fishing is $\pi_i = ph_i - C_i$. Substituting (1)-(3), and assuming that every country i chooses its effort, $E_i \geq 0$, and distance, $d_i \in [0, l + (n-1)(l-z)]$, so as to maximize profits, taking as given the choices of other countries, E_j and $d_j, j \neq i$, yields the Nash equilibrium in both effort and distance. As shown in the Appendix, the Nash equilibrium in distance is a corner solution: states will exploit the entire length of the fishery available to them. This is because, as noted before, distance and effort are equally effective at increasing the harvest, and increasing distance is the cheaper of the two options. The Nash equilibrium in distance is thus $d^{HM^*}(z) = L - (n-1)z$. Assuming an interior solution for every E_i, and substituting $d^{HM^*}(z)$ for d_i, gives the Nash equilibrium in effort:

$$E_i^{HM^*} = \frac{r}{\alpha(n+1)\theta(z)}\left\{1 - \frac{[c + \gamma\theta(z)L]}{p\alpha K\theta(z)}\right\}, \qquad (4)$$

where $\theta(z) = [L - (n-1)z]/L$ represents the fraction of the fishery to which every country has access. As the term in curly brackets is decreasing in z, and z must satisfy $z \in [0, l]$, effort will be given by (4) so long as fishing is profitable even when countries are confined to fishing within their own line segments (an enclosed sea). Henceforth, I shall assume that this last condition is satisified.

Setting $n = 1$ in (4) gives the usual "sole owner" solution for effort, apart from the distance term: $E_{sole\ owner}^{HM} = (r/2\alpha)[1 - (c + \gamma L)/p\alpha K]$. In the usual model, $L = 0$, as fishing takes place on a point (see, for example, eq. (2.2) in Clark 1976). An agreeable feature of my model is that it relates rather obviously to the non-spatial model that has long underpinned fisheries economics.

The solution for the offshore fishery is a little more complicated. In a highly migratory fishery, access to the fishery is restricted for *any* positive z. In an offshore fishery, access is restricted iff $z > l - w$, making the Nash equilibrium in distance $d^{OS^*} = L -$

$(n-1)z$, the same value as for the highly migratory fishery. Upon substituting, the Nash equilibrium in effort is

$$E_i^{OS^*} = \frac{r}{\alpha(n+1)\varphi(z)}\left\{1 - \frac{[c+\gamma\theta(z)]}{p\alpha K\varphi(z)}\right\}, \qquad (5a)$$

where $\varphi(z) = [w + (n-1)(l-z)]/wn$. In the offshore fishery, access is unrestricted if $z \leq l - w$. In this case, $d^{OS^*} = l + (n-1)w$, and equilibrium effort is

$$E_i^{OS^*} = \frac{r}{\alpha(n+1)}\left\{1 - \frac{[c+\gamma[l+w(n-1)]]}{p\alpha K}\right\}. \qquad (5b)$$

Again, the terms in curly brackets in (5a) and (5b) will be positive provided it pays every country to fish within its own line segment. Setting $n = 1$ in (5b) gives the sole owner solution: $E_{sole\ owner}^{OS} = (r/2\alpha)[1-(c+\gamma L)/p\alpha K]$. It may seem surprising that this should be the same as for the highly migratory fishery, but, with $n = 1$, both fisheries consist of a single line segment of length L; and, in both, the sole owner traverses the full length of the ocean to exploit a resource having the same carrying capacity (the fact that, in the offshore fishery, the sole owner must first cross a distance L – W before it can exploit the resource doesn't affect its choice of effort).

As every nearshore fishery is ecologically independent of the others, we can focus on the *i*th such fishery. It will obviously pay i to exploit its adjacent fishery. Given the symmetry of the ocean, it is also obvious that, if it pays any other country to exploit fishery i, it will pay every other country to exploit fishery i. Assuming that this last condition is satisfied, $d_i^{i*} = s$ and, $\forall j \neq i, d_j^{i*} = 2l - z$. Assuming an interior solution, *global* effort in the Nash equilibrium is the sum of the following two terms:

$$E_i^{NS_i^*} = \frac{r}{\alpha(n+1)}\left\{1 - \frac{\{c[1-n(1-\phi(z))] + \gamma[sn - z - 2(n-1)l]\}}{p\alpha k\phi(z)}\right\}, \qquad (6a)$$

$$\sum_{j \neq i} E_j^{NS_i^*} = \frac{r(n-1)}{\alpha(n+1)\phi(z)} \left\{ 1 - \frac{\{c[2-\phi(z)] + \gamma(4l - s - z)\}}{p\alpha k \phi(z)} \right\}, \qquad (6b)$$

where $\phi(z) = (s-z)/s$ represents the fraction of nearshore fishery i to which any country $j, j \neq i$, may gain access. It is easy to confirm from Eq. (6b) that, even if $z = 0$, every country j may prefer not to exploit fishery i. If every j *does* profit by exploiting fishery i for $z = 0$, increases in z will cause the term in curly brackets on the right side of (6b) to fall. If z reaches a critical value $\hat{z}^{NS}$,

$$\hat{z}^{NS} = \frac{s[p\alpha k - c - \gamma(4l - s)]}{p\alpha k + c - \gamma s}, \qquad (7)$$

(6b) will equal zero, and every j will exit the fishery, making i the sole owner. In this case, i will apply effort $E_{sole\ owner}^{NS} = (r/2\alpha)[1 - (c + \gamma s)/p\alpha k]$.[15]

Proposition 1 (Free-sea regime). *In an ocean subject to freedom of the seas* $(z = 0)$*, the "tragedy of the commons" for both highly migratory and offshore fisheries is due to excessive fishing effort, not excessive distance. For nearshore fisheries, effort and distance are both excessive when non-adjacent states also operate in the fishery, and both efficient when only the state adjacent to the fishery has an incentive to exploit it.*

This result anticipates much of what will follow. For highly migratory and offshore fisheries, if all coastal states retain the right to fish, efficiency requires limits on effort, not distance. By contrast, for nearshore fisheries, a limit on distance (property rights) suffices to sustain a first best by making the adjacent country the sole owner.

Proposition 2 (EEZ regime). *Starting from a free sea regime* $(z = 0)$*, incremental increases in the EEZ initially have marginal effects on exploitation of every fishery.*

---

[15] Eq. (6a) is derived assuming that every j applies a positive effort. The sole owner solution is found by setting $E_j^{NS_i} = 0$ in the first order condition for choice of $E_i^{NS_i}$.

(i) *For highly migratory and offshore fisheries, these effects remain marginal, with every state exploiting the entire range of the fishery on its own line segment and in any high-sea segments that lie beyond, until z reaches its maximum extent at $z = l$ and the seas are fully enclosed.*

(ii) *For nearshore fisheries, these effects remain marginal until z reaches $\hat{z}^{NS}$, at which point non-adjacent states exit the fishery and every coastal state becomes the de facto sole owner of the fishery adjacent to its homeport. Any EEZ in the range $z \in [\hat{z}^{NS}, s]$ suffices to exclude "foreign" fleets.*

5. The EEZ as an Equilibrium

In Section 4, property rights were given. Here I model choice of an EEZ and use the model to explain how and why the world adopted this new property right.

As noted in the introduction, property rights to the ocean are established in customary law. How to model this institution? Shaw (2003: 83) offers a vivid description of the process by which an existing customary rule stands or is replaced with reference to the territorial sea:

> "If a state proclaims a twelve-mile limit to its territorial sea in the belief that although the three-mile limit has been accepted law, the circumstances are so altering that a twelve-mile limit might now be treated as becoming law, it is vindicated if other states follow suit and a new rule of customary law is established. If other states reject the proposition, then the projected rule withers away and the original rule stands, reinforced by state practice and common acceptance."

It is striking how different this description is from the Nash assumption that countries choose an EEZ believing that other countries will *not* change their EEZs in response. Customary law is determined by a process of "claim and response." (Scharf 2013: 36). Under custom, country i chooses its EEZ believing that its choice will be accepted as law *only if (enough) other countries choose the same EEZ.* Shaw's description of beliefs suggests that establishment of an EEZ is the solution to the following game:

> **Stage 1**. Every i claims an EEZ of length z_i independently of the other states.
>
> **Stage 2**. An EEZ of length z, identical for each country, is established in customary law, and is thus binding upon all states, if and only if states claim this value by general agreement; otherwise, the pre-existing property rights arrangement stands.
>
> **Stage 3.** Every country chooses both effort and distance independently.

Previously, I took the property rights regime as given, focusing only on Stage 3. Here, the property rights regime is established in the preceding two stages. In creating the regime, countries anticipate, correctly, how it will change effort and distance subsequently. The sequencing is important. After all, the purpose of establishing an EEZ *is* to change where states fish. It should also be expected that effort may change—though by how much and in which direction is less obvious. Another way to understand the sequencing of this game is that property rights, however established, change very rarely, whereas distance and effort change all the time.

The Nash formulation of the property rights game consists of Stage 1 followed by Stage 3. Custom changes the rules of the game by adding Stage 2. If custom matters, the presence of the Stage 2 game will change how players choose in the other stages.

What constitutes "general agreement" in Stage 2? "[T]here exists no agreed-upon general formula for identifying how many states are needed….to generate a rule of customary international law" (Scharf 2013: 59). Instead, customary law "reflects the consensus approach to decision-making with the ability of the majority to create new law binding upon all…." (Shaw 2003: 70). In the customary law game, each state reasons backwards, claiming an EEZ in Stage 1 knowing that its choice will apply *universally* if and only if others support it. In a symmetric ocean, all players have the same preferences as regards a common EEZ, making consensus easy. The players' only remaining problem is coordinating choice of a *particular value* for the EEZ, a focal point that falls within the desired range. This is determined outside of my model.

Let us now solve for the Nash and customary law equilibria for property rights, beginning with the high-seas fishery. Under the Nash assumption, every i will choose $z_i \in [0, l]$ so as to maximize profits, believing that other states will not change their EEZ claims in response. This is the Stage 1 game. Before solving Stage 1, we must first solve Stage 3. In Section 4 I solved for the Nash equilibrium in effort and distance for a given *uniform* EEZ. Here, to solve the Stage 1 game, we need to know how distance and effort will change if i establishes a *different* EEZ than other countries.

We know from before that coastal state i can do no better than to exploit the full length of the fishery within its own EEZ and the lengths that lie in high sea areas beyond that. Hence, in Stage 3 we know that $d_i^{HM^*} = \theta L$ and $d_j^{HM^*} = L - (n-2)z - z_i$, where z is the EEZ established by every country $j, j \neq i$. In the Appendix I solve for $E_i^{HM^*}(z_i; z)$ and $E_j^{HM^*}(z_i; z), j \neq i$. To solve for the Stage 1 game, we only need to substitute these values into i's payoff function and calculate the Nash equilibrium in property rights. The solution, derived in the Appendix, is $z_{Nash}^{HM} = l$.

With property rights established in customary law, every state claims a property right in Stage 1 knowing that its claim will be established in customary law iff (enough) other countries make the same claim (Stage 2). This means that states effectively choose their preferred *universal* EEZ. To solve for this equilibrium, substitute $d^{HM^*}(z) = \theta L$ and $E^{HM^*}(z)$ from (4) into i's payoff function and then let i choose the *uniform* EEZ that maximizes its payoff. Given symmetry, every state makes the same claim in Stage 1, and so we can be sure that this claim will be established in customary law in Stage 2. The solution (see the Appendix) is $z_{Custom}^{HM} = 0$.

To sum up: in the Nash equilibrium, the seas are closed; in the customary law equilibrium, they are free. These solutions could not be more different.

Intuitively, under the Nash assumption that the EEZs of other countries are given, a coastal state can do no better than to extend its EEZ to the maximum limit. Country i benefits from this move if, by squeezing other states out of its EEZ, the harvests of every country $j, j \neq i$ fall, enlarging the stock available to i. However, though the stock increases under a regime of a fully enclosed ocean, positive distance costs lower profits relative to a free sea in which the EEZ is zero (see Fig. A.2 in the Appendix).

Under custom, every state refrains from extending its own EEZ knowing that its claim will only be lawful if other states assert the same claim. Intuitively, universal extension of the EEZ reduces each state's access to the resource (thus increasing costs) without reducing the number of states that gain access, the source of the tragedy of the commons. Custom urges restraint.

As I noted before, the highly migratory and offshore fisheries are closely related. They both comprise a single stock. As $w \to L/n$, they become equivalent. Unsurprisingly, their solutions are also equivalent. So long as it pays every coastal state to exploit the offshore fishery, even if only on its own line segment, $z_{Nash}^{OS} = l$ and $z_{Custom}^{OS} = 0$.

Finally, in the Nash equilibrium for nearshore fisheries, it will plainly pay every country adjacent to a fishery to increase its EEZ until "foreign" fleets exit the fishery (see Appendix). After all, by the Nash assumption, every country chooses its EEZ believing that other states will not change their EEZs in response. By contrast, when property rights are established in customary law, countries may be reluctant to extend their EEZ, knowing that, if they do, and if their claim is accepted in law, others will make the same claim. However, since the aggregate payoff is maximized when every country is the sole owner of its adjacent fishery (by removing the tragedy of the commons and reducing distance costs), and since, in a symmetric equilibrium, every country earns $1/n$th of the aggregate payoff, each can do no better than to claim an

EEZ that supports this outcome. Hence for nearshore fisheries, the Nash and customary law equilibria coincide: $z_{Nash}^{NS}, z_{Custom}^{NS} \in [\,\hat{z}^{NS}, l]$ (see Appendix).

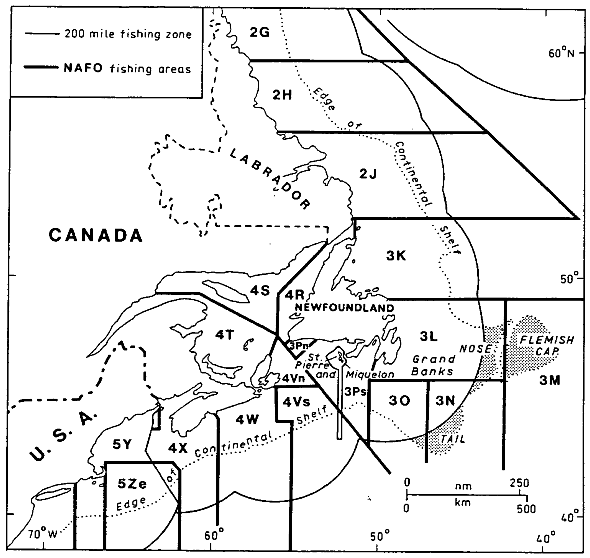
Proposition 3 (Customary law vs Nash equilibrium). *Customary law supports two different property rights regimes. For highly migratory and offshore stocks, custom urges restraint: the Nash impulse is to nationalize the seas completely, whereas custom supports a regime of freedom of the seas. For nearshore stocks, custom supports the same regime as the Nash equilibrium: creation of an EEZ of sufficient length to make every coastal state the sole owner of its adjacent nearshore fishery.*

The most striking result in Proposition 3 is that, were it not for custom, the ocean would be fully nationalized. For highly migratory and offshore stocks, the customary law and Nash equilibria could not be more different. Of course, freedom on the high seas is inefficient. But full enclosure of the seas, in my model, is even less efficient. Enclosure limits distance without reducing the number of countries having access.

In challenging the view that custom impinges on Nash behavior, Goldsmith and Posner (1999) offer as evidence the three-mile territorial sea, and completely ignore the regimes of freedom of the seas and an EEZ (let alone a 12-mile territorial sea). Proposition 3 suggests that they picked a situation that comes closest to supporting their interpretation, and ignored ones that point in a different direction.

How to know whether the EEZ established in customary law differs from the Nash equilibrium? As noted previously, the richest fishing grounds are to be found inside the continental shelf, usually within 200 miles from shore. However, in a few places, the continental shelf extends further than this. If custom merely codified the Nash equilibrium, EEZ limits should exceed 200-miles in these cases, and they don't. A prominent example is the "Nose" and "Tail" of the Grand Banks, which lie just beyond Canada's EEZ in the Northwest Atlantic; see Figure 6. In 2002, following years of overfishing in these waters by foreign fleets, a Canadian parliamentary committee rejected a proposal for Canada to assert unilateral control over these areas. "Few countries would benefit directly from an extension of EEZs over the continental shelf," the Committee concluded, implying that Canada could only get away with extending its EEZ if other countries adopted the same rule, as would be required if such a modification were to be supported by customary law.[16] Canada's adherence to the 200-mile limit, despite the implications for efficiency (due to the weakness of this region's RFMO, the Northwest Atlantic Fisheries Organization), is strong evidence of customary law's sway over state behavior.

Figure 6. Straddling Stocks Off the Grand Banks



Source: Freestone (1995), Figure 1, p. 398.

What explains the timing of the EEZ's creation? As noted previously, one reason could be an increase in n. Another could be technical change, which can be represented as an increase in α.[17] Focusing on nearshore fisheries, eq. (6b) shows that an increase in n and/or α would trigger entry and/or an intensification of exploitation of every i's adjacent fishery by every country j. Similarly, eq. (7) shows that an increase in n and/or α would cause every i to want to expand its EEZ claim.

[16] Canada House of Commons Standing Committee on Fisheries and Oceans, *Foreign Overfishing: Its Impacts and Solutions*, June 2002, p. 18.
[17] See Squires and Vestergaard (2013) for a much richer model of technical change in fishing.

Finally, Proposition 3 predicts that custom will favor different regimes for different stocks—in particular, enclosure of near-shore fisheries, but freedom to fish highly migratory species even within the EEZs. During the Law of the Sea negotiations, some states asserted this so-called "species approach." Others argued that coastal state jurisdiction should apply to *all* stocks—the "zonal approach" (recall from Section 2 that many early claims to a 200-mile exclusion zone were motivated by a desire to limit access to highly migratory stocks, from whales to tuna). To understand this dispute and how it came to be resolved, we need to model a "regional sea" and introduce a new type of player, the "distant water state."

6. Property Rights in a Regional Sea

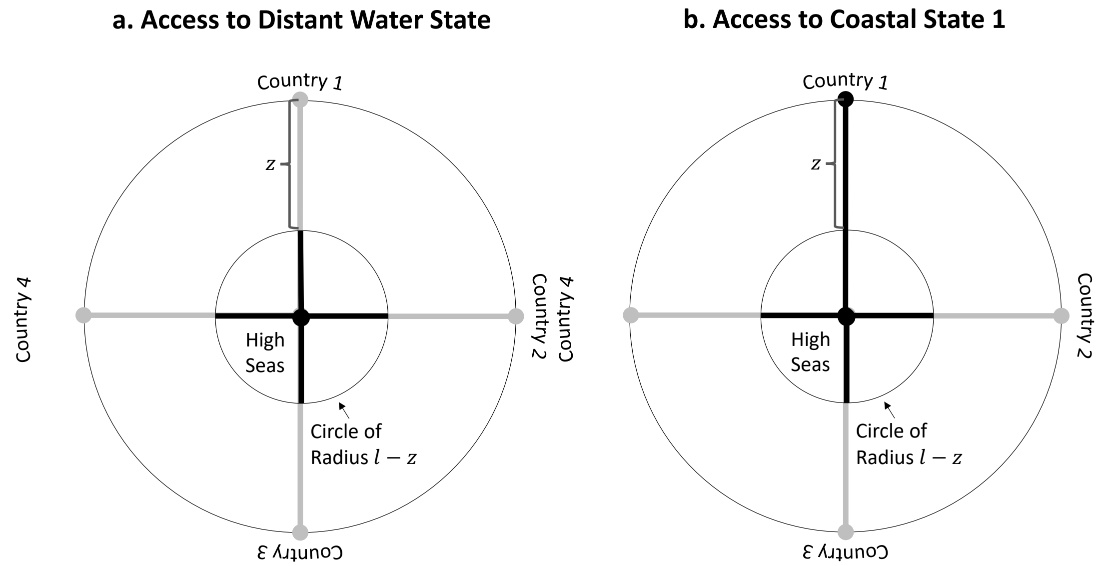
The UN Food and Agriculture Organization divides the ocean into 19 non-overlapping fishing areas (see in Figure 1), and defines distant water states as countries that fish outside of their own two-hundred-mile zones.[18] In the analysis that follows, a "regional sea" can be thought of as representing either one of these fishing areas or the territory of a regional fishery management organization.

How to model distant water fishing costs? States that fish far from home don't simply export their local fleets; they design fleets for the purpose of fishing a long way from home. They may even build port and processing facilities abroad. As well, the economics of distant water fishing may have less to do with absolute cost than comparative advantage in fishing (Munro 1989). Finally, distant water fleets are often subsidized, either directly or through weak labor market protection, if not outright forced labor (Sala et al. 2018). Lacking specific information about costs, let c^{DW} represent the cost of distant water fishing effort, inclusive of the cost of transporting a fleet of size E^{DW} *to* the regional sea, and γ^{DW} the fleet's distance cost once *inside* the regional sea. Without loss of generality, assume that every distant

[18] Eighty-six percent of the world's fish harvest is caught within a country's own EEZ or an adjacent EEZ, the rest in more distant EEZs (12 percent) and in the high seas (two percent) (Carlson et al. 2020).

water state enters the regional sea via the homeport of a coastal state. Then distant water states, upon arriving at such a port, must first travel a distance z just to get to the fishery, and, from there, traverse the high seas area to fish. By contrast, every coastal state may fish both on the high seas *and* within its EEZ. See Figure 7.

Figure 7. The Regional Sea



It can be shown (see Appendix) that participation in the regional fishery is profitable for distant water states iff

$$\left\{1+\frac{n[c+\gamma\theta(z)L]}{p\alpha K\theta(z)}\right\} > \frac{(n+1)[c^{DW}+\gamma^{DW}\theta(z)L]}{p\alpha K[\theta(z)-z/L]}, \tag{8}$$

where all the parameters in (8) now pertain to the regional sea—that is, n now denotes the number of coastal states in this sea, c these states' unit cost of effort, etc. Setting $z = 0$, we see that distant water states will fish in these waters so long as their costs are not unduly high relative to costs facing coastal states. As $z \to l$, however, the inequality in (8) reverses sign. That is, there exists an EEZ limit, $\hat{z}^{DW}, \hat{z}^{DW} \in (0, l)$, such that any $z \geq \hat{z}^{DW}$ induces distant water states to exit the fishery.

Will coastal states in a regional sea want to establish such an EEZ? They will if they would gain more by excluding distant water states than they would lose by being excluded from the EEZs of the other coastal states. Solving for $\hat{z}^{DW}$ is messy, but we know that, if coastal states can gain by setting $z = l$, then they will certainly gain by choosing an EEZ of length $\hat{z}^{DW}$. To simplify even further, assume $c = c^{DW}$ and $\gamma = \gamma^{DW}$. Then (see Appendix), coastal states will prefer an EEZ that induces distant water states to leave the fishery if $\pi_i(l) \geq \pi_i(0)$, or $N \geq \underline{N}$, where N denotes the number of distant water states and

$$\underline{N} = \frac{(n-1)(n+1)c}{p\alpha K[1-(cn+\gamma L)/p\alpha K]}. \tag{9}$$

The denominator of (9) will be positive so long as coastal states profit by fishing a distance l in the regional sea. Assume that this condition is met. Then we see immediately that, if $n = 1$, the lone coastal state will want to exclude distant water states and become the sole owner, as in a nearshore fishery. For higher values of n, coastal states will be more tolerant of distant water fishing. This is because, as n increases, l decreases (see Fig. 3), raising the cost of exclusion.[19]

Exclusion redistributes rents. It also changes aggregate payoffs, both by dampening the tragedy of the commons and by constraining distance. It can be shown that exclusion increases the aggregate payoff if and only if $N > \underline{\underline{N}} > \underline{N}$, where $\underline{\underline{N}}$ is characterized in the Appendix.

Proposition 4 (EEZs in a Regional Sea). *In a regional sea* $(with\ n \geq 2)$ *harboring a highly migratory stock, coastal states will wish to establish an EEZ in customary law of sufficient breadth* $(z \in [\hat{z}^{DW}, l])$ *to deter entry by distant water states if* N *is sufficiently large (with* $N \geq \underline{N}$ *being sufficient); otherwise, coastal states will favor a free seas*

[19] If coastal states could cooperate, both by excluding distant water states through customary law *and* by granting one another reciprocal free access, they would be even better off. If, in addition, they could limit their total harvest to the sole owner level, they would be as well off as possible.

regime. Distant water states, by contrast, will always favor a free seas regime. An EEZ enhances efficiency overall if and only if $N > \underline{\underline{N}} > \underline{N}$.

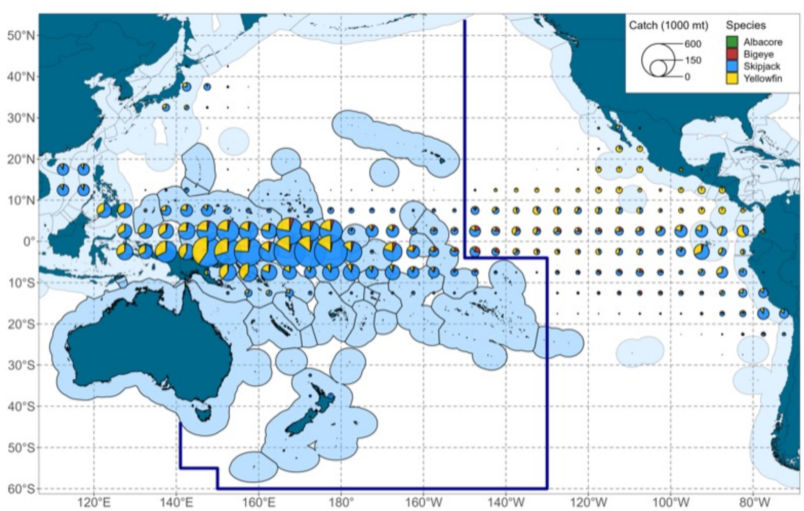
In a symmetric ocean, we know that the seas will be nationalized in the Nash equilibrium and free in the customary law equilibrium. In a regional sea, the Nash impulse is the same. However, if N is sufficiently large, coastal states will want customary law to enclose the regional sea, and distant water states will want custom to keep it free. In a regional sea, there will be conflict.

From the time the EEZ first emerged, the United States, a powerful distant water state, held that tuna stocks should be excluded from coastal state jurisdiction, and tuna harvests regulated by RFMOs (Munro 1990). Proposition 3 offers support for this position in a symmetric ocean. But because most of the US tuna catch was taken off the coasts of Chile, Ecuador, and Peru at this time, and not in waters closer to home, the US position appeared self-serving. Reinforcing this view, members of the RFMO in this region, the Inter-American Tropical Tuna Commission, were unable to agree on an allocation rule. The State Department's top fisheries policy officer "dismissed from the outset any thought that a management regime would allocate the fish harvest on some equitable or other basis among the nations involved in the fishery." Instead, he advocated allocating a total allowable catch to "whoever gets there first..." an approach that greatly favored US tuna clippers (Scheiber 2004: 44). Having no better option, coastal states thus sought to secure the allocation they wanted through their 200-mile sovereignty claims (Friedheim 1993).

The dispute played out at sea. The US government urged its tuna fleet to ignore coastal state claims to sovereignty; coastal states fined and seized the catches of US tuna boats fishing in their EEZs; and the US government reimbursed its nationals so as to encourage their continuing defiance. Both sides in this "Tuna War" had to act in opposition if their different interpretations of the scope of the EEZ were to have any chance of becoming law.

Over time, local fleets in the Eastern Tropical Pacific expanded, and US operators, growing weary of the conflict, relocated to the Central and Western Pacific. Here, another tuna war ensued; but, here, cohesion among archipelagic states, coupled with a willingness by the US's Cold War rival, the USSR, to negotiate access agreements, weakened US resolve. Geography also played a role. As shown in Figure 8, much of the tuna harvest in the Eastern Tropical Pacific is taken in the high seas. By contrast, in the Central and Western Pacific, the biggest share by far is caught in EEZ waters. Only in the latter regional sea could a 200-mile zone can achieve what theory says an EEZ of length $\hat{z}^{DW}$ ought to be able to achieve: impel distant water states to withdraw.[20] The first blow to the species approach came in 1987, when the US agreed to pay Pacific Island states for the right to catch tuna within their EEZs. The final blow came in 1991, when the US removed the tuna exception from its own legal claim to an EEZ. Only then was the scope of the EEZ finally determined in customary law.

Figure 8. Purse Seine Tuna Catch in the Pacific Ocean, 2016-2020

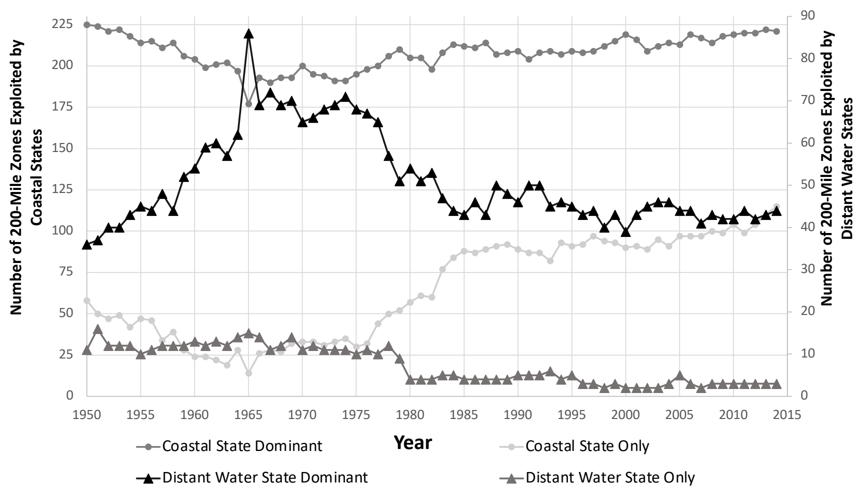


Source: Hare et al. (2022), Figure 5, p. 41.

[20] As if to prove this assertion, in 2008, a coalition of eight Pacific Island states effectively closed high seas "pockets" to purse-seiners by making fishing within their EEZs under license agreements conditional on distant water states not fishing in the pockets.

Figure 9 shows that establishment of the EEZ changed the identities of states fishing within 200 miles of shore. Before the EEZ, distant water states came increasingly to dominate in these waters; afterwards, coastal states regained this “lost ground.” Before, the number of 200-mile zones fished exclusively by coastal and distant states more or less held steady; afterwards, coastal states gained, and distant water states lost, ground in these categories. The shift in rents was even greater than suggested by these trends. Once the EEZ became law, coastal states demanded, and received, payment for access to “their” resource.

Figure 9. Coastal State vs Distant Water Dominance Within 200 Miles of Shore

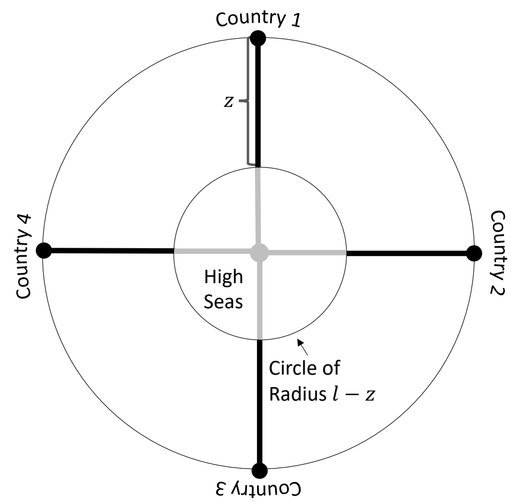


Source: Carlson et al. (2020), Table S14.

7. Close the high seas?

Would a ban on high seas fishing limit overfishing of highly migratory stocks? Would it increase rents? Would it be supported in customary law? If the high seas are closed to fishing, property rights will appear as in Figure 10.

Figure 10. Closure of the High Seas



Suppose a uniform EEZ of length z is in place. Taking both z and closure of the high seas as given, the Nash equilibrium in effort (see Appendix) is

$$E_i^{Closed^*}(z) = \frac{rL}{\alpha z(n+1)}\left[1 - \frac{(c+\gamma z)L}{p\alpha K z}\right] \tag{10}$$

for $z > \underline{z}$, where $\underline{z} = cL/(p\alpha K - \gamma L)$, and $E_i^{Closed^*} = 0$ for $z \leq \underline{z}$. For fishing to be profitable, states must have access to a sufficiently large stock. With the high seas closed to fishing, this means that the EEZ must be of a sufficient breadth. In the Appendix I show that stocks are higher, and payoffs lower, under a closed high-seas compared to an open one for $z < l$. Closing the high seas is inefficient, and so would not be supported in customary law—as, indeed, it has not been (at least, thus far).

Proposition 5. *In a symmetric ocean, the collective payoff to exploiting a highly migratory fishery is higher when there is freedom throughout the seas (no EEZ) than when the seas are fully enclosed, and higher when the seas are fully enclosed than when there exists an EEZ short of the maximum breadth and fishing on the high seas is banned. A high seas ban is neither efficient nor supportable as an equilibrium in customary law.*

White and Costello's (2014) ranking of payoffs is the reverse of the one described in Proposition 5. Why the contrast? It is difficult to know for sure. Their model differs from mine in numerous ways. However, a clue as to the reason is that their ranking of stocks is the same as in my model.[21] Very likely, two assumptions are critical. First, White and Costello assume that costs decrease in the stock. This seems reasonable, though the use of fish aggregating devices substantially reduces the importance of stock size for harvesting costs. Second, in common with the wider literature, White and Costello ignore distance costs. Essentially, their results hinge on costs falling with the stock and mine with costs falling with distance. It is remarkable that two outwardly reasonable models could arrive at opposite conclusions about a change in property rights as profound as closing the high seas to fishing.

International law allows one exception to freedom of the high seas. The Law of the Sea recognizes that "states of origin" of anadromous species—salmon, which spawn in inland waters—have a "primary interest in and responsibility for such stocks." It also instructs such states to fish for salmon "only in waters landward of the outer limits of the exclusive economic zones." As this provision is accepted by consensus, and reinforced by state practice, Burke (1991: 118) finds "that the customary international law of freedom of fishing no longer affords any right to harvest [anadromous species] without the agreement of the state of origin," an effective ban on directed fishing for salmon in the high seas. Because salmon move throughout the EEZs of different states of origin in the North Pacific, the ban transforms what would have been a resource available to n coastal plus N distant water states into one owned in common by just n states. Given that custom prohibits EEZs from extending further than 200-miles, closure of the high seas for these species may be the next-best means for excluding distant water states from this fishery.

8. Conclusions

[21] Compare Fig. A.2 in the Appendix with White and Costello's Fig. 2.

I present a spatial model of the ocean (a single dimension, set in a two-dimensional frame) in which property rights are determined in customary international law. According to the model, the exclusive economic zone emerged to exclude foreign fleets from exploiting stocks near to a coastal state's shores. Though this conclusion isn't surprising, my model explains several puzzling features of the property rights regime, such as why freedom on the seas prevailed historically (this arrangement being an equilibrium in customary law and not a Nash equilibrium), why this regime changed in the 1970s (the reason being an increase in fishing activity by foreign vessels, spurred in part by technical change and decolonization), why the EEZ jumped from zero to 200 miles instead of being inched up incrementally (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 foreign vessels to exit the fishery).

Legal scholars have debated whether customary law determines behavior or whether behaviors interpreted as evidence of adherence to custom would have occurred in the law's absence. In a symmetric ocean, I find that the customary and Nash behavior coincide in some situations and diverge in others. In all situations, however, I find that customary law favors more efficient over less efficient outcomes. In an asymmetric, regional sea, I find that custom is determined by the relative power of coastal and distant water states, and need not promote efficiency. These results offer a more complex view of custom than can be found in the legal literature.

My model also offers a different way of looking at proposals to change the current regime, from nationalizing the ocean to closing the high seas. I find that both changes would be harmful to coastal states in a symmetric ocean, and for this reason would not be adopted in customary law.

My model is highly abstract. The ocean, its resources, and institutions like customary law that govern their exploitation, are all vastly more complex than represented here. Topics that could be explored in future research include: the dynamics of the underlying processes, including transition paths to steady states; alternative assumptions regarding the geography of the ocean and the spatial distribution of fish stocks, including how harvest costs vary in these dimensions; alternative representations of distance costs, including distant water fishing costs; allowing price to vary with the harvest; omitted ecological features such as the location of spawning grounds, patterns of larval dispersion, inter-species interactions, and changes in environmental conditions; endogenizing compliance with, and enforcement of, EEZs; and the many reasons besides fisheries management that the law of the sea changed in the 1970s, and why, even today, the rules governing access to the ocean's resources continue to be challenged. Most importantly, as my model suggests that property rights are an imperfect means for overcoming the tragedy of the ocean commons, more research is needed into strategies to enforce cooperative fisheries agreements.

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Online Appendix

A.1 EEZ given

Here I derive equilibrium stocks for the three fisheries.

A.1.1 Stocks

Substituting (1) into (2) for each fishery and rearranging gives: for the highly migratory fishery,

$$x = K\left(1 - \frac{\alpha}{rL}\sum_{i=1}^{n} E_i d_i\right) \tag{A.1a}$$

for $d_i \in [0, L-(n-1)z]$; for the offshore fishery,

$$x = K\left(1 - \frac{\alpha}{rwn}\sum_{i=1}^{n} E_i (d_i - l + w)\right) \tag{A.1b}$$

for $d_i \in [l-w, L-(n-1)z]$ if $z > l-w$, and for $d_i \in [l-w, l+(n-1)w]$ if $z \leq l-w$; and, finally, for nearshore fishery i, assuming $s > z$ and that the fishery is exploited by all n countries,

$$x^i = k\left[1 - \frac{\alpha}{rs}\left(E_i^i d_i^i + \sum_{j \neq i}^{n} E_j^i \left[d_j^i - (2l - s)\right]\right)\right] \tag{A.1c}$$

for $d_i^i \in [0, s], d_j^i \in [2l-s, 2l-z]$ for $i, j = 1, \ldots n, i \neq j$.

A.1.2 Equilibrium distance and effort

Here I solve for the Nash equilibrium in distance and effort for all three fisheries.

A.1.2.1 The highly migratory fishery

Coastal state i's profit from exploiting a highly migratory fishery is $\pi_i = ph_i - C_i$ or, upon substituting (1) and (A.1a),

$$\pi_i^{HM} = p\alpha K E_i \frac{d_i}{L}\left[1 - \frac{\alpha}{rL}\left(E_i d_i + \sum_{j \neq i} E_j d_j\right)\right] - (c + \gamma d_i)E_i. \qquad (\text{A}.2)$$

Every country i maximizes (A.2) by choosing $E_i \geq 0$ and $d_i \in [0, L - (n-1)z]$, taking as given $E_j, d_j, j \neq i$. Assuming an interior solution, maximization by choice of E_i requires

$$d_i\left\{\frac{p\alpha K}{L}\left[1 - \frac{\alpha}{rL}\left(2E_i d_i + \sum_{j \neq i} E_j d_j\right)\right] - \gamma\right\} = c \qquad (A.3)$$

Write the Lagrangian as $\mathcal{L}_i^{HM} = \pi_i^{HM} + \lambda\theta(z)L$, where λ is the multiplier for the constraint $d_i \leq \theta(z)L$, and where $\theta(z) = [L - (n-1)z]/L$. Maximization by choice of d_i gives:

$$E_i\left\{\frac{p\alpha K}{L}\left[1 - \frac{\alpha}{rL}\left(2E_i d_i + \sum_{j \neq i} E_j d_j\right)\right] - \gamma\right\} = \lambda \qquad (A.4)$$

We know from (A.3) that if equilibrium effort is positive, the term in curly brackets in (A.3) is positive. But if this term is positive, then (A.4) says that λ must be positive, so that $d_i^* = \theta(z)L$. Countries exploiting a fishery will always want to cover as much of the territory as they can. Substituting the Nash equilibrium in distance into (A.3) and assuming a symmetric solution gives eq. (4), the Nash equilibrium in effort. Profit in the Nash equilibrium is

$$\pi_i^*(z) = \frac{prK}{(n+1)^2}\left[1 - \frac{[c + \gamma\theta(z)L]}{p\alpha K\theta(z)}\right]^2. \qquad (A.5)$$

A.1.2.2 The offshore fishery

For the offshore fishery, assuming $z \leq l - w$, coastal state i maximizes

$$\pi_i^{OS} = p\alpha K E_i \frac{(d_i - l + w)}{wn} \times \left[1 - \frac{\alpha}{rwn}\left(E_i(d_i - l + w) + \sum_{j \neq i} E_j\left(d_j - l + w\right)\right)\right] - (c + \gamma d_i)E_i. \qquad (A.6)$$

If $z > l - w$, the EEZ overlaps with the offshore fishery. In this case, every i maximizes (A.6) but with $d_i - l - (n-1)(l - z)$ substituted for $d_i - l + w$. As we found for the highly migratory fishery, it can be shown that, if i exploits *any* of the offshore fishery, it will want to exploit *all* of the offshore fishery available to it. If the EEZ and offshore fishery do not overlap, the Nash equilibrium in distance will be $d_i^{OS^*} = l + (n-1)w$. If the EEZ and offshore fishery overlap, $d_i^{OS^*} = L - (n-1)z$. Maximizing (A.6) with respect to effort and substituting gives eq. (5a) for $z > l - w$ and (5b) for $z \leq l - w$.

A.1.2.3 The nearshore fishery

As each nearshore fishery is ecologically independent of the others, we can focus on exploitation of the ith nearshore fishery:

$$\pi_j^{NS_i} = p\alpha k E_j^i \frac{\left(d_j^i - \delta_j(2l-s)\right)}{s}\left[1 - \frac{\alpha}{rs}\sum_{j=1}^{n} E_j^i\left(d_j^i - \delta_j(2l-s)\right)\right] - \left(c + \gamma d_j^i\right)E_j^i, \qquad (A.7)$$

for all $i, j = 1, \dots, n,$ where $\delta_j = 0$ for $j = i$ and $\delta_j = 1$ for $j \neq i$; $d_i^i \in [0, s]$ and $d_j^i \in [0, 2l - z]$; and $s > z$. Again, we know that, if it pays a country to exploit nearshore fishery i, it will pay the country to exploit the full length of the fishery available to it. In a Nash equilibrium, therefore, $d_i^{i^*} = s$ and $d_j^{i^*} = 2l - z$, provided $E_j^{i^*} > 0$. Eqs. (6a)-(6b) are derived by substituting these values into (A.7) and maximizing this expression with respect to effort. If z is sufficiently large, it will not pay any $j, j \neq i$, to enter the fishery (this is obviously true if $z \geq s$). Eq. (7) is found by setting the term in curly brackets in (6b) equal to zero. To derive the sole owner's effort, set $E_j^i = 0 \forall j, j \neq i$, in (A.7) and maximize this expression for $j = i$.

A.2 Choice of EEZ

Here I derive choice of an EEZ for all three fisheries under the Nash and customary law assumptions.

A.2.1 Highly migratory fishery

Country i chooses an EEZ, z_i, $z_i \in [0, L/n]$, to maximize

$$\pi_i^{HM} = \frac{p\alpha K(L - z_{-i})E_i^*}{L}\left\{1 - \frac{\alpha}{rL}\left[(L - z_{-i})E_i^* + \sum_{j \neq i}(L - z_{-j})E_j^*\right]\right\} - [c + \gamma(L - z_{-i})]E_i^* \qquad (A.8)$$

where $z_{-i} = \sum_{j \neq i} z_j$ and $z_{-j} = \sum_{v \neq j, v \neq i} z_v + z_i$. Here, I have already substituted the Nash equilibrium values for distance. E_i^* and E_j^* represent the Nash equilibrium values for effort, and these need to be solved for.

Maximization of (A.8) for i and of the corresponding payoff functions for every j, $j \neq i$ gives

$$E_i^* = \frac{r}{\alpha(n+1)\psi_i(z)}\left\{1 - \frac{\{c[n\psi_j(z,z_i) - (n-1)\psi_i(z)] + \gamma L\psi_i(z)\psi_j(z,z_i)\}}{p\alpha K\psi_i(z)\psi_j(z,z_i)}\right\} \quad (A.9a)$$

$$E_j^* = \frac{r}{\alpha(n+1)\psi_j(z,z_i)}\left\{1 - \frac{\{c[2\psi_i(z) - \psi_j(z,z_i)] + \gamma L\psi_i(z)\psi_j(z,z_i)\}}{p\alpha K\psi_i(z)\psi_j(z,z_i)}\right\}, \quad (A.9b)$$

where $\psi_i(z) = [L - z(n-1)]/L$, $\psi_j(z,z_i) = [L - z(n-2) - z_i]/L$, and z represents the (symmetric) EEZ established by every country other than i. Both of these solutions are identical to (4) for $z_i = z$. It can be shown that $2\psi_i(z) - \psi_j(z,z_i) > n\psi_j(z,z_i) - (n-1)\psi_i(z)$ and that $\psi_i(z) > \psi_j(z,z_i)$ for $z_i > z$. Hence it isn't obvious which country will exert more effort, i or j, should i increase its EEZ.

Substituting these solutions back into (A.8) gives

$$\pi_i = \frac{prK}{(n+1)^2}\left\{1 - \frac{[c[n\psi_j(z,z_i) - (n-1)\psi_i(z)] + \gamma L\psi_i(z)\psi_j(z,z_i)]}{p\alpha K\psi_i(z)\psi_j(z,z_i)}\right\}^2. \quad (A.10)$$

Maximizing the Lagrangian incorporating (A.10) by choice of z_i subject to $z_i \in [0, l]$ requires

$$\frac{2rc(n-1)}{\alpha(n+1)^2 L\psi_j^2}\left\{1 - \frac{[c[n\psi_j(z,z_i) - (n-1)\psi_i(z)] + \gamma L\psi_i(z)\psi_j(z,z_i)]}{p\alpha K\psi_i(z)\psi_j(z,z_i)}\right\} + \mu - \lambda = 0 \quad (A.11)$$

where λ is the Lagrange multiplier on the constraint $z_i \leq l$ and μ is the multiplier on the constraint $z_i \geq 0$. In a symmetric Nash equilibrium, $z_i = z$, and the term in curly brackets in (A.11) will be positive so long as it pays every country to fish only within its own line segment. This means that λ must be positive, which implies that the Nash equilibrium is $z_{Nash}^{HM} = l$.

With property rights established in customary law, states choose their preferred *universal* EEZ. Letting $z_i = z$, and substituting the Nash equilibrium values for d_i and E_i gives

$$\pi_i = \frac{prK}{(n+1)^2}\left\{1 - \frac{\{c + \gamma L\psi_i(z)\}}{p\alpha K\psi_i(z)}\right\}^2. \qquad (A.12)$$

It is easy to show that $d\pi_i/dz < 0$, and so once again we obtain a corner solution, only here the equilibrium is $z_{Custom}^{HM} = 0$

A.2.2 Offshore fishery

The situation for an offshore fishery is akin to that of a highly migratory fishery; a formal proof isn't needed. In the Nash equilibrium, the offshore fishery is partitioned into national sections, whereas in the equilibrium in customary law, the offshore fishery remains a high seas fishery, open to all.

A.2.3 Nearshore fishery

In a Nash equilibrium, country i chooses its EEZ, z_i, to maximize its payoff, taking as given the EEZs claimed by every country $j, j \neq i$. We know that, in a Nash equilibrium, i will always fish a distance s, and j a distance $2l - z_i$, for $z_i < \hat{z}^{NS}$. We can therefore rewrite (A.7) as

$$\pi_i^{NS_i} = p\alpha K E_i^i(z_i)\left[1 - \frac{\alpha}{r}\left(E_i^i(z_i) + \sum_{j=1, j\neq i}^{n} E_j^i(z_i)\phi(z_i)\right)\right] - (c + \gamma s)E_i^i(z_i). \quad (A.13a)$$

Using the Nash equilibrium values for E_i^i and E_j^i, we can rewrite (A.13a) as

$$\pi_i^{NS_i} = \frac{p\alpha K E_i^i(z_i)}{(n+1)}\left[1 + \frac{\left[c[(n-1) - \phi(z_i)] + \gamma[2(n-1)l - sn + z_i]\right]}{p\alpha K \phi(z_i)}\right]. \qquad (A.13b)$$

The term in curly brackets plainly increases in z_i. Differentiating eq. (6a) with respect to z_i shows that the E_i^i also increases in z_i. Hence, in a Nash equilibrium, every i will increase its EEZ until "foreign" fleets exit the fishery; that is, $z_{Nash}^{NS} \in [\,\hat{z}^{NS}, l]$. Moreover, since this outcome is efficient, this EEZ will also be the one that all states would wish were the universal EEZ; $z_{Custom}^{NS} = z_{Nash}^{NS} \in [\,\hat{z}^{NS}, l]$.

A.3 Regional sea

Here I derive the calculations behind Section 6.

A.3.1 Incentive for Distant Water States to Participate in the Fishery

Under the assumption that every distant water state enters the regional fishery from a coastal state's homeport, every distant water (superscript DW) state i will choose its effort level to maximize

$$\begin{gathered}\pi_i^{DW} = p\alpha K E_i^{DW}[\theta(z) - z/L] \times \\ \left\{1 - \frac{\alpha}{r}\left[\left(E_i^{DW} + \sum_{j \neq i}^{N} E_j^{DW}\right)[\theta(z) - z/L] + nE^{CS}\theta(z)\right]\right\} \\ -[c^{DW} + \gamma^{DW}\theta(z)L]E_i^{DW}.\end{gathered} \qquad (A.14)$$

where n now denotes the number of coastal states in the regional sea and N the number of distant water states, and where, to conserve notation, I leave out superscripts for coastal states. Substituting (4) for E, and maximizing the Lagrangian corresponding to (A.14), participation in the fishery by distant water states is rational iff (8) holds. Both sides of (8) increase in z. The rate of increase is higher for the RHS term than the LHS term if

$$\frac{(n+1)[nc^{DW}+\gamma^{DW}L]}{n(n-1)c} > \left(\frac{L-nz}{L-(n-1)z}\right)^2. \qquad (A.15)$$

The RHS of (A.15) equals 1 for $z = 0$, is decreasing in z for $z \in (0, l)$, and equals 0 for $z = l$. Hence, if the LHS of (A.15) is greater than one, we know that there exists a unique value for z—call it $\hat{z}^{DW}, \hat{z}^{DW} \in (0, l)$—such that, for any $z \in [\hat{z}^{DW}, l]$, distant water states will exit the fishery. This condition is satisfied rather easily. For example, it will be satisfied if $c^{DW} \geq c$ and $\gamma^{DW} \geq 0$. The precise value of $\hat{z}^{DW}$ is found by setting the LHS of (8) equal to the RHS and is a messy quadratic equation. Rather than solve explicitly for $\hat{z}^{DW}$, I consider the implications of coastal states setting $z = l$. If coastal states can profit by setting $z = l$ we know that they can profit even more by setting a somewhat lower value, one that still deters distant water entry.

A.3.2 Incentive for Coastal States to Deter Entry by Distant Water States

Will coastal states gain or lose by deterring entry? To know, we need to compare the payoffs coastal states get if they allow entry by distant water states by setting $z = 0$, or deter entry by setting $z = l$.

If they allow entry, every coastal state *i* will choose its effort level to maximize

$$\pi_i = p\alpha K E_i \theta(z)\left\{1 - \frac{\alpha}{r}\left[\left(E_i + \sum_{j\neq i}^{n} E_j\right)\theta(z) + NE^{DW}[\theta(z) - z/L]\right]\right\} - [c + \gamma\theta(z)L]E_i. \qquad (A.16)$$

Similarly, every distant water state *i* will choose its effort level to maximize (A.14). The Nash equilibrium effort levels are:

$$E = \frac{r}{\alpha(n+N+1)\theta(z)}\left\{1 - \frac{(N+1)[c+\gamma\theta(z)L]}{p\alpha K\theta(z)} + \frac{N[c^{DW}+\gamma^{DW}\theta(z)L]}{p\alpha K[\theta(z)-z/L]}\right\} \quad (A.17a)$$

$$E^{DW} = \frac{r}{\alpha(n+N+1)[\theta(z)-z/L]}\left\{1 - \frac{(n+1)[c^{DW}+\gamma^{DW}\theta(z)L]}{p\alpha K[\theta(z)-z/L]} + \frac{n[c+\gamma\theta(z)L]}{p\alpha K\theta(z)}\right\} \quad \text{(A.17b)}$$

Upon substituting (A.17a) and (A.17b) into (A.16), we find that, if coastal states accommodate entry by distant water states, coastal state *i* will earn

$$\pi_i = \frac{prK}{(n+N+1)^2}\left[1 - \frac{(N+1)[c+\gamma\theta(z)L]}{p\alpha K\theta(z)} + \frac{N[c^{DW}+\gamma^{DW}\theta(z)L]}{p\alpha K[\theta(z)-z/L]}\right]^2. \quad (A.18)$$

Upon substituting we get, for $z = 0$,

$$\pi_i(0) = \frac{prK}{(n+N+1)^2}\left[1 - \frac{(c+\gamma L)}{p\alpha K} - \frac{N(c+\gamma L - c^{DW} - \gamma^{DW}L)}{p\alpha K}\right]^2. \quad (A.19a)$$

If coastal states set $z = l$, distant water states will obviously be excluded, giving coastal state *i*

$$\pi_i(l) = \frac{prK}{(n+1)^2}\left[1 - \frac{(cn+\gamma L)}{p\alpha K}\right]^2. \quad (A.19b)$$

Coastal states will prefer adoption of an EEZ that drives distant water states out of the fishery if $\pi_i(l) \geq \pi_i(0)$, or $N \geq \underline{N}$, where

$$\underline{N} = \frac{c(n-1)(n+1)/p\alpha K}{\left[1 - \frac{(cn+\gamma L)}{p\alpha K}\right] + \left[\frac{(n+1)(c+\gamma L - c^{DW} - \gamma^{DW}L)}{p\alpha K}\right]}. \quad (A.20)$$

As indicated in the paper, the first term in the denominator will be positive so long as it pays coastal states to fish a distance l in the regional sea. The second term in the denominator represents coastal states' cost-advantage/disadvantage over distant water states (assumed to be zero in eq. (9)). To see the effect of cost differences, start by assuming that coastal and distant water states have identical costs. Then, for $n > 1$, $\underline{N}$ will be positive. If distant water states have a slight cost advantage, $\underline{N}$ will fall; coastal states will be less tolerant of distant water fishing. If instead coastal states have a slight cost advantage, they will be more tolerant of distant water states. This last term reflects the tension that exists in using the EEZ as a way to manage the fishery: exclusion reduces the tragedy of the commons, but at the expense of each coastal state having to accept a limit on its own access.

A.3.3 Effect of Entry Deterrence on Aggregate Payoffs

Pushing out distant water states reduces the tragedy of the commons, but at the cost of limiting access to the fishery by coastal states. Does exclusion increase payoffs overall? Assume that coastal and distant water states have identical costs. Then, if $z = 0$, both will have the same payoff:

$$\pi_i(0) = \pi_i^{DW}(0) = \frac{prK}{(n+N+1)^2}\left[1 - \frac{(c+\gamma L)}{p\alpha K}\right]^2. \qquad (A.21)$$

Coastal states will gain by pushing distant water states out if $\pi_i(l) \geq \pi_i(0)$. Substituting (A.19b) and (A.21), $\pi_i(l) \geq \pi_i(0)$ implies

$$\frac{n}{(n+1)^2}\left[1 - \frac{(cn+\gamma L)}{p\alpha K}\right]^2 \geq \frac{n}{(n+N+1)^2}\left[1 - \frac{(c+\gamma L)}{p\alpha K}\right]^2. \qquad (A.22)$$

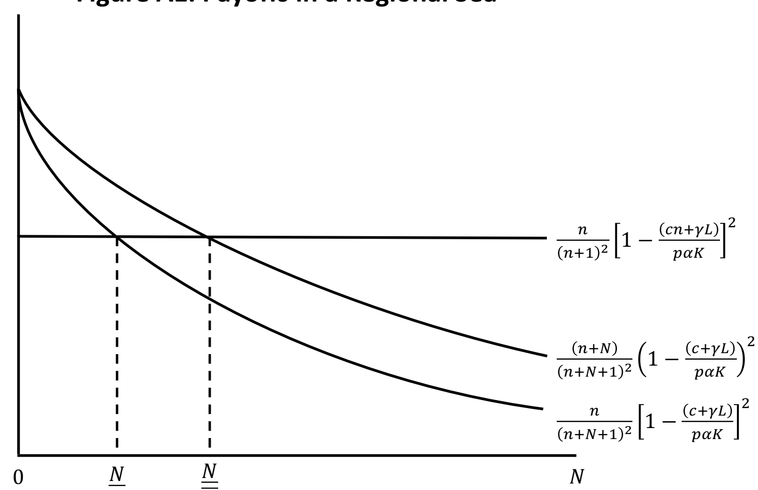
Eq. (9) is found by making (A.22) an equality and solving for N. That is, setting $N = \underline{N}$ makes (A.22) an equality.

Exclusion will increase payoffs overall if $n\pi_i(L/n) \geq n\pi_i(0) + N\pi_i^{DW}(0)$ or

$$\frac{n}{(n+1)^2}\left(1 - \frac{(cn + \gamma L)}{p\alpha K}\right)^2 \geq \frac{(n+N)}{(n+N+1)^2}\left(1 - \frac{(c + \gamma L)}{p\alpha K}\right)^2. \qquad (A.23)$$

Let $\underline{\underline{N}}$ denote the value of N that makes (A.23) an equality. If $N > \underline{N}$, coastal states do better by setting $z = l$, thereby excluding distant water states from the regional fishery. If $N > \underline{\underline{N}}$, aggregate payoffs increase when distant water states are excluded. Again, the solutions to $\underline{N}$ and $\underline{\underline{N}}$ are rather messy, but they are easily represented qualitatively; see Figure A.1.

Figure A1. Payoffs in a Regional Sea



A.4 Close the High Seas?

A.4.1 Proof of Proposition 5

Assume that z is small enough so that it is optimal for coastal states to exploit the fishery if the high seas are closed. Then, every coastal state i will choose effort to maximize

$$\pi_i^{Closed} = p\alpha K E_i \frac{z}{L}\left[1 - \frac{\alpha z}{rL}\left(E_i + \sum_{j\neq i} E_j\right)\right] - (c + \gamma z)E_i. \qquad (A.24)$$

Maximization of (A.24) yields eq. (10). Substituting the Nash equilibrium in effort into (A.24) gives

$$\pi_i^{Closed^*}(z) = \frac{prK}{(n+1)^2}\left[1 - \frac{(c+\gamma z)L}{p\alpha K z}\right]^2. \qquad (A.25)$$

If the high seas are closed, payoffs are increasing in z (decreasing in the length of the high seas). Proposition 5 asserts: $\pi_i^{Open^*}(0) > \pi_i^{Open^*}(l) > \pi_i^{Closed^*}(z)$. We can derive $\pi_i^{Open^*}(0)$ and $\pi_i^{Open^*}(l)$ from (A.5):

$$\pi_i^{Open^*}(0) = \frac{prK}{(n+1)^2}\left[1 - \frac{(c+\gamma L)}{p\alpha K}\right]^2. \qquad (A.26a)$$

$$\pi_i^{Open^*}(l) = \frac{prK}{(n+1)^2}\left[1 - \frac{(cn+\gamma L)}{p\alpha K}\right]^2. \qquad (A.26b)$$

$\pi_i^{Open^*}(0) > \pi_i^{Open^*}(l)$ requires:

$$\frac{prK}{(n+1)^2}\left[1 - \frac{(c+\gamma L)}{p\alpha K}\right]^2 > \frac{prK}{(n+1)^2}\left[1 - \frac{(cn+\gamma L)}{p\alpha K}\right]^2, \qquad (A.27a)$$

or $\pi_i^{Open^*}(0) > \pi_i^{Open^*}(l) \Leftrightarrow n > 1$. Similarly, $\pi_i^{Open^*}(l) > \pi_i^{Closed}(z)$, requires

$$\frac{prK}{(n+1)^2}\left[1-\frac{(cn+\gamma L)}{p\alpha K}\right]^2 > \frac{prK}{(n+1)^2}\left[1-\frac{(c+\gamma z)L}{p\alpha Kz}\right]^2, \qquad (A.27b)$$

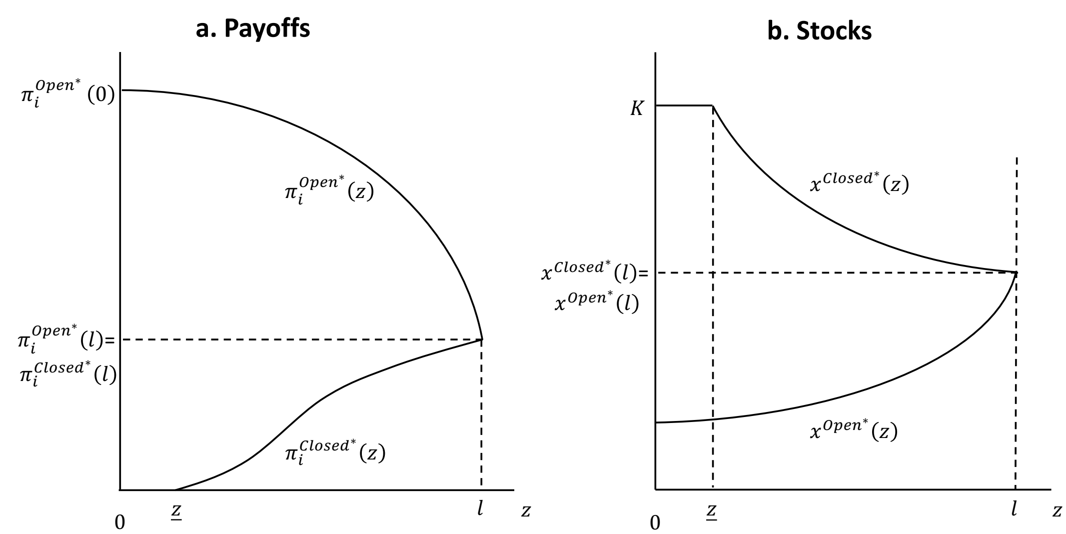
so that $\pi_i^{Open^*}(l) > \pi_i^{Closed}(z) \Leftrightarrow z < l$.

Plainly, closure of the high seas ban is inefficient. Moreover, we know that closure cannot be supported as an equilibrium in customary law because coastal states will be better off if the high seas are open than if they are closed.

A.4.2 Stocks and Payoffs for an Open and Closed High Seas

Figure A.2 shows how payoffs and stocks vary with the property rights regime. These figures can be compared directly with Figure 2 in White and Costello (2014).

Figure A.2. Payoffs and Stocks for an Open and Closed High Seas



Start with Figure A.2.a. This figure shows two payoff relations. The first is the payoff to fishing for highly migratory stocks when the high seas are free. This payoff is

$$\pi_i^{Open^*}(z) = \frac{prK}{(n+1)^2}\left[1 - \frac{[c + \gamma\theta(z)L]}{p\alpha K\theta(z)}\right]^2. \qquad (A.28)$$

It is easy to show that the first and second derivatives of (A.28) are negative for $n > 1$. We also know the end points in the figure. If $z = 0, \theta(0) = 1$; and if $z = l, \theta(l) = 1/n$. Eq. (A.26a) gives $\pi_i^{Open^*}(0)$ and eq. (A.26b) $\pi_i^{Open^*}(l)$.

$\pi_i^{Closed}(z)$ is given by (A.25). It is apparent that, if the high seas are closed, z must be sufficiently large for fishing to be profitable. In particular, we require

$$(p\alpha K - \gamma L)\frac{z}{L} \geq c. \qquad (A.29)$$

The LHS is the profit obtained by deploying a small increment of effort optimally (meaning, over the entirety of the ocean), when the stock is at its maximum (carrying capacity) multiplied by the proportion of the ocean that a country is able to exploit. The RHS is the cost of the small unit of effort needed to obtain this profit. For $z > \underline{z}, \underline{z} = cL/(p\alpha K - \gamma L)$, the derivative of $\pi_i^{Closed^*}$ is positive and increasing until z reaches $2\underline{z}$, the inflection point. For z greater than $2\underline{z}$, the second derivative is negative. Figure A.2.a is drawn assuming that $\underline{z} < l$, though this needn't be the case. Of course, $\pi_i^{Open}(l) = \pi_i^{Closed}(l)$.

Turn now to Figure A.2.b, which shows the corresponding values for stocks. These relations are

$$x^{Open^*}(z) = K\left\{1 - \frac{n}{(n+1)}\left[1 - \frac{[c + \gamma\theta(z)L]}{p\alpha K\theta(z)}\right]\right\} \qquad (A.30a)$$

$$x^{Closed^*}(z) = K\left\{1 - \frac{n}{(n+1)}\left[1 - \frac{[(c + \gamma z)L]}{p\alpha Kz}\right]\right\} \qquad (A.30b)$$

For (A.30a), it is easy to show that the intercept is positive and that the first and second derivatives are increasing. For (A.30b) we know that it will not pay to apply a positive effort until z reaches $\underline{z}$. Hence, for EEZs smaller than this, the stock will equal carrying capacity. Beyond this, effort will be positive, and the stock reduced. For $z \in [\underline{z}, l]$, the first derivative of (A.30b) is decreasing and the second increasing. Of course, $x^{Open^*}(l) = x^{Closed^*}(l)$.