Are Open Access Fisheries Really Preferable? A Comment on "Property Rights to the World's (Linear) Ocean Fisheries"

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Abstract. Barrett (2024) provides a highly engaging and enlightening model of the emergence of exclusive economic zones (EEZs) in the world's fisheries. Among other results, he reaches the surprising conclusion that, for highly migratory fisheries, open access is more efficient than privatization—even when there are no monitoring and enforcement costs. In this comment, I show that this result is fragile, and that introducing some intensity of effort along with a cost externality overturns his finding. Consistent with economic intuition, private property is more efficient than open access.

JEL Codes: D23, F55, Q22, Q28

Key Words: Ocean fisheries, closure of high seas, common property, tragedy of the commons, private property.

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1 Introduction

In his prize-winning article in the *Journal of the Association of Environmental and Resource Economists*, Barrett (2024) provides a highly engaging and enlightening model of the emergence of exclusive economic zones (EEZs) in the world's fisheries. It provides important insights into the timing of the emergence of EEZs, the focal-point nature of their 200-mile limit, and their potential to increase as well as redistribute resource rents.

Alongside these fascinating insights, Barrett reaches what I believe to be a more surprising and controversial conclusion. To wit:

> **Proposition 5**: [T]he 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. (p. 714)

In other words, in terms of economic efficiency, the relative ranking of property rights regimes on the high seas is (1) open access; (2) private property (with EEZs extended into them); and (3) protecting them in a conservation zone. This conclusion applies to "highly migratory fisheries," which are uniformly spread across the sea in Barrett's model. The efficiency of a high seas ban, or creating marine protected areas, is a nuanced and controversial one, though his conclusion that they are inefficient for highly migratory fish is unusual (see Albers and Ashworth 2022 for a review).

Much more surprising is the claim that open access throughout the entire ocean is always more efficient than any private property (let alone full enclosure). This conclusion contradicts conventional wisdom in political economy. In fact, a great part of the history of the development of the entire field of environmental economics has focused on institutions that can close or manage the commons (Banzhaf 2023). If open access were to turn out to be more efficient, that would be an important result indeed.

However, as I show in this comment, Barrett's results stem from two restrictive modeling assumptions. First, he assumes one fisher's activity at a location is binary: either it fishes or doesn't. Consequently, conditional on total fleet size, the only way to increase fishing activity is to pile more players on top of each other. Allowing individual players to have some intensity of effort weakens his conclusion. Second, the only externality is through the stock, and stocks migrate instantaneously. Allowing a cost or productivity externality, as in many textbook models of the commons, fully reverses his conclusion: in line with standard intuition, privatizing the commons leads to efficiency gains.

To my knowledge, the literature has found only three types of exceptions to the rule that private property is more efficient than open access. The first is when property rights are costly to monitor and enforce. If they are high enough, these transaction costs may exceed any gains in resource rents from enclosure (Demsetz 1964; Anderson and Hill 1983). For example, open range land on the American West may have been the most efficient arrangement, until the invention of barbed wire reduced the cost of enforcing private property rights (Anderson and Hill 1975). The second exception is when property rights in one location, again costly to enforce, cause externalities in other locations, possibly leading to an expensive race to enforcement. For example, a burglar defense system at one house causes the burglars to just go next door, which causes the neighbors to get the defense system, and so on (De Meza and Gould 1992). The third exception is when enclosing a resource creates monopoly power in the output market (Clark 1990; Manning and Uchida 2016).

In the case of the high seas, the issue of costly monitoring fishing activity and enforcing property rights is especially salient. However, it is not present in Barrett's model, and nor are any of the others, so they cannot lie behind his results. What can account for them? Barrett himself seems surprised by how his results differ from others', such as White and Costello (2014), the paper closest to his, which finds the complete opposite ranking from his Proposition 5. "Why the contrast?" he asks. He conjectures that

> 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 [per unit of catch] falling with stock and mine with costs falling with distance. It is remarkable that the two outwardly reasonable models could arrive at opposite conclusions.... (p. 715)

As I discuss in this note, Barrett's conjecture about the two critical assumptions is correct—and in fact highlight the problem with his model. While much of the model is reasonable and appropriate to his other research questions, these aspects are less appropriate for the questions addressed in Proposition 5.

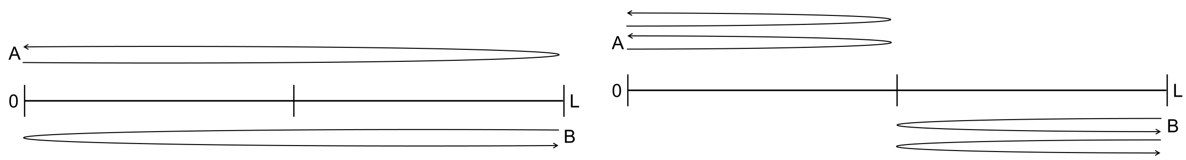
2 Summary of Barrett's Model with Commentary

Barrett (2024) creatively introduces a circular sea, with fishing fleets based at home ports arranged along the perimeter of the circle. His broader agenda is to model international rules governing the oceans, so players in his model are nations. Although for purposes of deriving Proposition 5 his model is sufficiently general that it could apply to many other settings, I will continue to refer to players as nations. National fleets travel a one-way distance d along the radius of the circle towards the center, and from there potentially back out again along all the radii corresponding to other nations' home ports. (Of course, they also sail back home again, but they only fish while out-bound, which is a harmless normalization.) The total one-way length that potentially can be traveled is L, and if there are n countries the circle has radius $l = L/n$. With freedom of the seas, fleets are always allowed to travel anywhere, but they may only fish inside their own EEZ or on the high seas—they may not fish in other nations' EEZs (see, e.g., Barrett's Figure 4). Denote the length of each country's EEZ as z, with $0 \leq z \leq L/n$.

With the highly migratory fishery, the fish stock, x, is always uniformly distributed in space with density x/L. Then the stock accessed by a nation i is $x_i = xd_i/L$ for $d_i \in [0,\ l + (n-1)(l-z)]$ (p. 700). With complete open access ($z = 0$), nations can go up to a length $d_i = L$ and if they do then $x_i = x\ \forall\ i$.

Costs of effort are $C_i = (c + \gamma d_i)E_i$ (Equation 3). Although Barrett describes E_i as representing effort, it may better be thought of as a Ricardian capital-labor bundle (e.g. a boat together with its crew), as he describes c as "the cost of boats and crews sitting in their home port" (p. 702). There is no actual effort until the boats start sailing, so henceforth I will refer to d_iE_i as "effort." (Pedantry aside, I make this point as it has some interpretive significance for my proposed generalization, below.) In any case, we then have harvest $h_i = \alpha x_i E_i$ (Equation 1). Substituting for the definition of x_i given above, $h_i = \alpha x d_i E_i/L$. Finally, the model is static and taken at the steady state using the Gordon-Schaefer growth equation. See Barrett (2024) for further details.

For the highly migratory fishery, an optimum has $z = 0$ and all nations' vessels traveling the full distance to the center and back out along all other nations' radii. For the case of $n = 2$, this optimum can be depicted on a simple line of length $L = 2l$, i.e., the circle's diameter. As depicted in Figure 1a, Nation A is located at zero, on the far left, and Nation B at L, on the far right. At Barrett's optimum, each nation will send E_i boats all the way across the line (and back). As shown in the figure, each point on the linear ocean is fished twice, once by each nation (recalling they only fish while outbound).



(a) Open access with both nations crossing high seas once

(b) Full enclosure with each nation crossing its EEZ twice

Figure 1: Open Access vs. Enclosure, with Intensity of Effort

Why not send twice as many boats half as far? As Barrett explains, it is because more boats involves the fixed startup cost c, whereas going farther does not (p. 702). Overcapitalizing with more boats is inefficient relative to utilizing fewer boats more intensively. Nevertheless, it seems odd that fleets *must* overlap—that there is no way to divide up the sea with the same number of boats covering it.

3 Introducing Intensity of Effort

This anomaly can be overcome with a simple expedient: introducing some notion of spatially-delineated intensity of effort. For example, why not allow nations to cover the same strip of sea repeatedly? Intuitively, for $n = 2$, having each nation travel l (in one-way distance) twice should be equivalent to each traveling $2l$ once. This solution is depicted in Figure 1b. As with panel a, each point on the sea is covered twice (outbound), but now always by the same fleet. The nations can divide up the sea and simply cover their half more intensively. But now, intensively isn't just through more E_i (which the model rules out in equilibrium), but more repeated trips.[1]

As noted previously, Barrett rightly points to his introduction of linear distance as one of the innovative parts of his model. This innovation is especially useful for his purpose of distinguishing between freedom of the seas (the right to pass through) from fishing rights, which in turn is especially useful for his comparative study of different types of fisheries. For example, in the case of nearshore fisheries, Barrett's model allows for the possibility that sometimes a nation's fleet travels across the high seas to another nation's coastal waters (e.g., the UK fishing off the coast of Iceland). For highly migratory

[1]The model remains timeless. Just as Barrett originally used the abstraction that fleets can travel any distance $d \leq L$ (and back) instantaneously, so they can instantaneously travel, say, $d/2$ twice. Too, just as time has been abstracted away, so has space been abstracted to a line, without the possibility of more crisscrosses across a patch. My notion of intensity might be thought of as a way to work around these abstractions.

fisheries, which are my focus here, linear distance is still useful as a way to demark a cutoff of EEZ's from the high seas.

However, I suggest the key issue driving Proposition 5 is not so much the introduction of distance, but the restriction that the only choices are distance and the number of boats. Consequently, the *only* two ways in the model to vary total fishing activity at a point are through either more boats or by stacking nations' activity on top of each other. With more boats having a startup cost, the conclusion ends up being that open access is more efficient, as it allows more fishing activity at a point with a given total fleet. But missing here is the possibility of a single nation exerting more effort at a point. There is no "circling about," or somehow "trying harder" as they go across the line. Total catch is a function of the product of $d_i E_i$, but at Barrett's optimum we go to a corner solution where every nation fishes every stretch of sea. In other words, the constraint on the size of the fishable world is binding.

But, significantly, so is the constraint that effort is binary: either a nation fishes a point on the line or not. To relax that assumption, let t_i denote the number of passes that nation i takes over its distance d_i. We assume the variable costs continue to be proportional to total distance covered, which is now $t_i d_i$. Thus, $C_i = (c + \gamma t_i d_i)E_i$. Likewise, because in Barrett's model fish are *always and instantaneously* distributed evenly, now $h_i = \alpha x(t_i d_i)E_i/L$.

It is easy to see that we have merely introduced a simple change of variables. Let $q_i = t_i d_i$. Then obviously we can solve for q_i just as Barrett solved for d_i. Everything is the same. And we are completely indifferent to any values of t_i, d_i that have the same product. They result in the same harvest, and they result in the same cost. So we can privatize the high seas, decreasing d_i, but increasing t_i to compensate.

This takes much of the sting out of Proposition 5. By this simple modeling expedient, we remove the conclusion that open access is strictly better than privatization. However, it does remain no worse.

4 Introducing Production Externalities

Why are we still at least indifferent between open access and privatization? Now we come to the other distinguishing feature of his model that Barrett identified—that there is no effect of stock on costs, or, more generally, that there is no productivity externality except through the steady-state stock. This focus on the dynamic externality was a feature of earlier classic models like Gordon (1954) (see also Scott 1955 for discussion). But, significantly, in Barrett's model, the effect through the steady-state stock actually bites equally under private property or open access. With instantaneous dispersal of the fish population—all countries everywhere and always fishing the same stock x—even with private property a country's effort affects others' x, just as it does with open access. Whether a country is one of n fishing the high seas or gets $1/n$ of the seas privately does not matter.

In contrast, canonical models like Weitzman (1974), Dasgupta and Heal (1979) and Cornes and Sandler (1996) introduce a static production externality, where in open access nations receive an effort-weighted share of joint output, determined by a concave function of joint effort. Through this jointness, nations impose an externality on others' productivity, which is internalized in the EEZ. By duality, this lower marginal product per unit input is equivalent to a higher marginal cost of output. In this vein, White and Costello (2014) work through the cost side, while also introducing a dynamic element: in any time period, fish stocks begin at x at a given location, but are fished down over the course of the period until dispersion occurs at the start of the next period. Thus, in their model too, there is a within-period cost externality at a given location under open access, which is internalized in the EEZ. But these externalities are not present in Barrett (2024).

Keeping the model static (which seems closer to Barrett's) and maintaining his "hub-and-spoke" geography, I address these issues by introducing the production externality as in Dasgupta and Heal (1979) and Cornes and Sandler (1996), with variable effort at each point on the line. Thus, at each location $l \in [0, L]$, nations target effort $q_i(l)$ as the control variable instead of d_i, recognizing that in principle distance can still be represented as the point at which q goes to zero. At any location with open access, $h_i(l) = \alpha \frac{x}{L} \frac{q_i(l)}{Q(l)} F(Q(l))$, where $Q(l) = \sum_j q_j(l)$ and where $F(\ )$ is a strictly increasing, strictly concave, twice differentiable production function, with $F(0) = 0$. In contrast, at any given point in the EEZ $h_i(l) = \alpha \frac{x}{L} F(q_i(l))$. Finally, to resolve a degeneracy introduced by including both fleet E_i and intensity of fishing, I set $c = 0$ (no startup costs for boats separately from effort) and simply solve for q_i.

With EEZ of length z, profits for country i are:

$$\pi_i = p\alpha\frac{x}{L}\left[\int_0^z F\left(q_i(l)\right)dl + \int_{nz}^{L}\frac{q_i(l)}{q_i(l)+\sum_{-i}q_j(l)}F\left(q_i(l)+\sum_{-i}q_j(l)\right)dl\right] - \gamma\left[\int_0^z q_i(l)dl + \int_{nz}^{L} q_i(l)dl\right]. \quad (1)$$

Following Barrett, I use the Gordon-Schaefer growth equation, so

$$x = K\left[1 - \frac{\alpha}{rL}\int_0^L F\left(\sum_j q_j(l)\right)dl\right] \quad (2)$$

in the steady state, with parameters $r > 0$ and $K > 0$.

Our strategy will be to find each nation's profit function and then find the optimal z, to re-evaluate the value of property rights. I assume nations do not account for their effects on the stock when optimizing.

In this model, for all nations j, all points within the open access area are equivalent, and so are all points within their respective EEZs. Thus, we can use the simplifying notation of a profit-maximizing q_i^{OA} for each point in open access and a q_i^{EEZ} for each point in the EEZ, as well as $Q^{OA} = \sum_j q_j^{OA}$. Additionally, *after* taking first order conditions, we can impose the assumption of a symmetric equilibrium. Doing so, the first-order conditions in each zone can be (re)written:

$$\frac{p\alpha x}{L}F'(q_i^{EEZ}) = \gamma \quad (3)$$

and

$$\frac{p\alpha x}{L}\left[\frac{1}{n}F'(Q^{OA}) + \frac{n-1}{n}\frac{F(Q^{OA})}{Q^{OA}}\right] = \gamma. \quad (4)$$

Eq. 3 for the EEZ represents a standard optimality condition: nations set marginal revenue equal to marginal cost. As there is no monopoly power in the output market, the condition is socially optimal, maximizing resource rents (given n and z). Eq. 4 represents the standard static condition that in the OA zone, nations set marginal cost equal to a weighted average of marginal revenue and average revenue (Cornes and Sandler 1996). As $n \to 1^+$, the marginal revenue term gets full weight, with no externalities. As $n \to \infty$, the average revenue term gets full weight, which represents the tragedy of the commons with complete dissipation of rents, so the model of Gordon (1954) is a limiting case. Given the concavity of $F(\ )$, $Q^{OA} > q^{EEZ}$, as one would expect.

Using only these assumptions and derived conditions, the following proposition holds:

Proposition. *Global profits are maximized with full enclosure of the commons:* $n\pi_i(L/n) > n\pi_i(z)\ \forall\ z \in [0, L/n)$.

Proof. See the appendix.

This proposition establishes that, when we modify Barrett's model to incorporate a notion of intensity of effort, his Proposition 5 no longer holds. To the contrary, the standard economic intuition that there are efficiency gains to closing the commons does hold. This result is also consistent with that of White and Costello (2014), although arriving there by a different path.

Nevertheless, as discussed at the outset, open access can in fact be an advantageous arrangement when monitoring and enforcement costs of closing it are sufficiently high (Anderson and Hill 1983). These costs have surely changed over the long sweep of history that Barrett discusses. Thus, it may be that, with falling enforcement costs, the desirability of closing the commons has only increased over time. Too, this paper, like Barrett (2024), has only considered the equilibrium steady state. Future research might consider the effect of (even constant) enforcement costs in a fully dynamic model, with falling stocks also creating a critical juncture at which it becomes desirable to close the high seas. Such a finding would resemble those from the land use literature, where, at an early stage in history, it initially is optimal to clearcut forests, depleting the stock, and then only at a critical juncture begin sustainable rotations (Hanley, Shogren, and White 1997, §10.5). It also would remain well within the spirit of Barrett's seminal paper.

References

Albers, Heidi J., and Madison F. Ashworth. 2022. Economics of marine protected areas: Assessing the literature for marine protected area network expansions. *Annual Review of Resource Economics* 14:533–554.

Anderson, Terry L., and Peter J. Hill. 1975. The evolution of property rights: A study of the American West. *The Journal of Law and Economics* 18 (1): 163–179.

Anderson, Terry L., and Peter J. Hill. 1983. Privatizing the commons: An improvement? *Southern Economic Journal* 50 (2): 438–50.

Banzhaf, H. Spencer. 2023. *Pricing the Priceless: A History of Environmental Economics.* Cambridge, UK: Cambridge University Press.

Barrett, Scott. 2024. Property rights to the world's (linear) ocean fisheries in customary international law. *Journal of the Association of Environmental and Resource Economists* 11 (3): 689–718.

Clark, Colin W. 1990. *Mathematical Bioeconomics: The Mathematics of Conservation.* 2nd ed. New York: Wiley.

Cornes, Richard, and Todd Sandler. 1996. *The Theory of Externalities, Public Goods, and Club Goods.* Cambridge University Press.

Dasgupta, Partha S, and Geoffrey M Heal. 1979. *Economic Theory and Exhaustible Resources.* Cambridge University Press.

De Meza, David, and J Robert Gould. 1992. The social efficiency of private decisions to enforce property rights. *Journal of Political Economy* 100 (3): 561–580.

Demsetz, Harold. 1964. The exchange and enforcement of property rights. *The Journal of Law and Economics* 7:11–26.

Gordon, H Scott. 1954. The economic theory of a common-property resource: The fishery. *Journal of Political Economy* 62 (2): 124–142.

Hanley, Nick, Jason F Shogren, and Ben White. 1997. *Environmental Economics: In Theory and Practice.* Springer.

Manning, Dale T., and Hirotsugu Uchida. 2016. Are two rents better than none? When monopolies correct ill-defined property rights. *Marine Resource Economics* 31 (2): 141–164.

Scott, Anthony. 1955. The fishery: The objectives of sole ownership. *Journal of Political Economy* 63 (2): 116–124.

Weitzman, Martin L. 1974. Free access vs private ownership as alternative systems for managing common property. *Journal of Economic Theory* 8 (2): 225–234.

White, Crow, and Christopher Costello. 2014. Close the high seas to fishing? *PLoS Biology* 12 (3): e1001826.

Appendix: Proof of the Proposition

This appendix proves the proposition that profits are maximized when the seas are totally enclosed (i.e., $z = L/n$). First, begin by introducing the following additional notation. Let π_i^{EEZ} and π_i^{OA} be optimized profits for nation i per unit of length in the EEZ and OA, respectively, with $\pi_i = z\pi_i^{EEZ} + (L - nz)\pi_i^{OA}$. Using this notation, we will next proceed through the following series of lemmas.

Lemma 1. *Equilibrium effort in the EEZ is increasing in the stock:* $\frac{q_i^{*EEZ}}{dx} > 0$.

Proof. From Eq. 3 (the first-order condition in the EEZ), define

$$G^{EEZ}(x, q_i^{*EEZ}) = p\alpha\frac{x}{L}F'(q_i^{*EEZ}) - \gamma \equiv 0. \tag{A1}$$

Totally differentiating G^{EEZ}, setting it equal to zero, and re-arranging:

$$dq_i^{*EEZ}/dx = -\frac{\partial G^{EEZ}/\partial x}{\partial G^{EEZ}/\partial q_i^{*EEZ}} = -\frac{F'(q_i^{*EEZ})}{xF''(q_i^{*EEZ})} > 0. \tag{A2}$$

The last inequality follows from the fact that F( ) is increasing and concave. □

Lemma 2. *Total equilibrium effort in zone OA is increasing in the stock:* $\frac{dQ^{*OA}}{dx} > 0$.

Proof. The proof is similar to that for the previous lemma. From Eq. 4 (the first-order condition in the OA zone), define

$$G^{OA}(x, Q^{*OA}) = p\alpha\frac{x}{L}\left[\frac{1}{n}F'(Q^{*OA}) + \frac{n-1}{n}\frac{F(Q^{*OA})}{Q^{*OA}}\right] - \gamma \equiv 0. \tag{A3}$$

Note that although no agent is optimizing Q^{OA}, we can still use the identity established by Eq. 4 and work with Q^{OA} instead of q_i^{OA}. Totally differentiating G^{OA}, setting it equal to zero, and re-arranging:

$$dQ^{*OA}/dx = -\frac{\frac{1}{n}F'(Q^{*OA}) + \frac{n-1}{n}\frac{F(Q^{*OA})}{Q^{*OA}}}{x\frac{1}{n}F''(Q^{*OA}) \ + \ x\frac{n-1}{n}\left[F'(Q^{*OA}) - \frac{F(Q^{*OA})}{Q^{*OA}}\right]\frac{1}{Q^{*OA}}} > 0. \tag{A4}$$

The numerator is clearly positive. Both terms in the denominator are negative, again by the concavity of $F(\ )$, which assures that the average return exceeds the marginal return. With the negative sign out front, the entire expression is then positive. $\square$

Lemma 3. *The stock is increasing in the length of the EEZ:* $\frac{dx}{dz} > 0$.

Proof. Re-write the stock equation as a function G^x of q_i^{*EEZ} and Q^{*OA}, which in turn are functions of x and z:

$$x \equiv G^x(x,z) = K\left\{ 1 - \frac{\alpha}{rL}\left[nzF\left(q_i^{*EEZ}(x,z)\right) + (L-nz)F\left(Q^{*OA}(x,z)\right)\right]\right\} \quad \text{(A5)}$$

Then $dx/dz = \partial G^x/\partial z + (\partial G^x/\partial x)(dx/dz)$. Or, rearranging,

$$dx/dz = \frac{\partial G^x/\partial z}{1 - \partial G^x/\partial x} = \frac{-\frac{K\alpha}{rL}n\left[F(q_i^{*EEZ}) - F(Q^{*OA}\right]}{1 + \frac{K\alpha}{rL}\left[nzF'(q_i^{*EEZ})\frac{dq_i^{*EEZ}}{dx} + (L-nz)F'(Q^{*OA})\frac{dQ^{*OA}}{dx}\right]} > 0. \quad \text{(A6)}$$

The numerator is positive because $Q^{OA} > q_i^{EEZ}$ and $F(\ )$ is increasing. Also, the entire term enclosed in square brackets in the denominator is positive, by Lemmas 1 and 2 and again the fact that F( ) is increasing. Thus, the entire expression is positive. $\square$

Lemma 4. *Profits at a point in the EEZ are increasing in the length of the EEZ:* $\frac{d\pi_i^{EEZ}}{dz} > 0$.

Proof. Begin with the expression for profits in the EEZ at a point: $\pi_i^{EEZ} = p\alpha\frac{x}{L}F(q_i^{*EEZ}) - \gamma F(q_i^{*EEZ})$ and observe that:

$$\frac{d\pi_i^{EEZ}}{dz} = \frac{\partial\pi_i^{EEZ}}{\partial x}\frac{dx}{dz} + \left.\frac{\partial\pi_i^{EEZ}}{\partial q_i^{EEZ}}\right|_{q_i^{*EEZ}}\frac{dq_i^{*EEZ}}{dz} > 0. \quad \text{(A7)}$$

The second term is zero by the envelope theorem. In the first term, it is easy to see that $\partial\pi_i^{EEZ}/\partial x > 0$, from the above expression for profits. Additionally, $dx/dz > 0$ by Lemma 3. Thus, the entire expression is positive. $\square$

Lemma 5. *Profits at a point in the EEZ are higher than in the open access area:* $\pi_i^{EEZ} > \pi_i^{OA}$.

Proof. Note that the stock x is the same in both zones, so the only thing driving differences in profits is behavior. In the EEZ, nations choose effort to guarantee π_i^{EEZ} is at a maximum. By contrast, in the OA zone, other nations' actions create a negative externality on nation i. (One can easily verify that $\partial\pi_i^{OA}/\partial q_{-i}^{OA} < 0$.) $\square$

We are now in a position to prove the main proposition of the paper.

Proof of the Proposition.
Writing profits as a function of z only, $\pi_i(L/n) = (L/n)\pi_i^{EEZ}(L/n) > (L/n)\pi_i^{EEZ}(z) > z\pi_i^{EEZ}(z) + (L - nz)\pi_i^{OA}(z) = \pi_i(z), \forall\ z \in [0, L/n)$. The first equality is simply the definition of profits when $z = L/n$. The second expression follows from Lemma 4, that profits at a point in the EEZ are increasing in z. The third expression follows from Lemma 5, that profits at a point in the EEZ are higher than at a point in the OA zone, for given x. The last equality is again just a definition of profits at some arbitrary $z < L/z$. $\square$

Interestingly, profits may not necessarily be *monotonically* increasing in z, at least not for all concave $F(\ )$. The issue is that, by Lemma 2, the resulting increase in stocks x increases the total effort in the OA zone, which can actually decrease the profits in that zone if the additional externalities offset the direct effect of the enhanced stock. Moreover, over certain intervals, this effect can exceed the other beneficial effects. However, this reversal only happens under a combination of the following three circumstances, which must all hold:[2]

(i) The number of nations is sufficiently small. In the limit as $n \to \infty$, profits in the OA go to zero for any z, so there are no profits to lose from that zone anyway. This effect can dominate if n is large enough.

(ii) The EEZ is sufficiently small. As $z \to L/n$, the length of the OA zone $(L - nz)$ vanishes, so again there are no profits to lose from it anyway. This effect can dominate if z is large enough. Note this implies that profits must be increasing in z near the boundary $z = L/n$, which, since the profit function is continuous, is logically consistent with that point being a global maximum.

(iii) $F(Q)$ is "very concave." In particular, the elasticity $F'(Q)\frac{Q}{F}$ must change rapidly over some interval of Q, which is the interval where π_i may be decreasing in z. At this point, the open-access externalities suddenly become severe enough to offset the

[2]These conditions, especially the third, were derived with the assistance of Claude AI.

other effects. Many standard production functions do not exhibit this property. For example, a constant-elasticity production function such as $F(Q) = aQ^{\theta}$, for $a > 0$ and $0 < \theta < 1$, is sufficient to guarantee that profits are strictly monotonic in z.

Regardless of the curious possibility of such an interval, the Proposition establishing that total enclosure is socially optimal holds for any n and any concave, twice differentiable $F(\ )$.