Open Access Performance When Vessels Use Profit Goal Behavior

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Abstract. While most bioeconomic models assume that vessel operators use profit maximizing behavior, it is sometimes argued that participants use other operational goals. The purpose of this paper is to compare how vessel behavior, the bioeconomic equilibrium and the path to achieve it are changed if participants use profit goal behavior. It is shown that, depending on the operational rule used to achieve the profit goal, there can be significant differences in the amount of individual vessel effort at different stock sizes, and this can effect the location and the stability of the bioeconomic equilibrium.

Keywords: Profit maximizing behavior, profit goal behavior, open-access fishery behavior.

1. INTRODUCTION

This paper is motivated by a series of discussions I have had over the years, principally with non-economists, about the behavior of industry participants as the stock becomes overfished. It was often contended that individual operators would compensate for stock reductions by increasing effort. The implication was that what appeared to be a rational individual response, in the aggregate only made a bad situation worse. The stock would fall even further perhaps making it difficult to achieve a stable bioeconomic equilibrium even when there is vessel exit due to negative long-term profits. I would make the counter arguement that if vessel profitability decreases with stock size, then if operators use profit maximizing behavior, PMB, they would reduce effort as stock size decreased. This reduction would reinforce the effect of reduced fleet size, thus speeding stock recovery and increasing the probability of achieving a stable bioeconomic equilibrium. Indeed, it is easy to construct a formal model based on PMB that demonstrates that this will be the case. See below.

But this may very well miss the point. What if individual vessel behavior is based on something other than profit maximization? Is it possible to specify behavior where individual vessel effort will increase with decreases in stock size? One possible scenario is where individual operators determine vessel activity based on the desire to achieve a specified profit goal. Call this PGB, for profit goal behavior. The effects of PGB have been analyzed in some industries, but not, to the best of my knowledge, in open access fisheries. The obvious question is what level of profits will vessel operators choose as a goal. Without loss of generality, it can be assumed that they shoot for a level of annual net returns that will exactly cover fixed costs. This can be justified on the notion that, properly defined, FC includes the full opportunity cost of alternative uses of human and physical capital. A lower profit goal will not allow for a viable operation. While a higher goal is possible, it will only affect the stock size at which the profit goal can not be met, (see the discussion below), it will not affect the qualitative nature of the results.

The purpose of this paper is to provide a preliminary analysis that compares the operation of a fishery where participants maximize profits with an otherwise identical fishery where participants use PGB. The items to be compared are individual vessel behavior, stock and fleet size at the bioeconomic equilibrium, and the likely nature of the time path of stock and fleet size as the fishery approaches the equilibrium.

The paper will proceed as follows. The first main section introduces a standard bioeconomic model that can be used to make the proposed comparisons. Because the discussion can be facilitated by a graphical analysis, explicit functions with hypothetical parameter values will be used. The next section describes four different operational rules that will allow vessels to achieve a profit goal. Emphasis will be given to the ability to achieve the profit goal with changes in stock size and to issues of vessel entry and exit given that when the goal is met, vessel profit will not vary with stock size. A discussion of how the functional relationships of the bioeconomic model are altered for each of the four operational rules is also included. The fourth section compares and contrasts vessel behavior, the bioeconomic equilibrium, and the time path of the fishery for profit maximization and profit goal achievement. The next section introduces other issues that arise given the possibility of PGB. The final section provides a summary and offers suggestions for further research.

2. The Bioeconomic Fishery Model.

The relevant issues can be captured in a Vernon Smith type model, Smith (1969), where the vessel operator can choose both the amount of effort produced per day, e, and the number of days fished per season, d. Assume homogeneous vessels with the following daily profit function.

$$B(X, e) = PqXe - v_1 e - v_2 e^2 \qquad (1)$$

P is price of fish, qXe is the vessel daily production function, (q is the catchability coefficient, and X is the stock size), and $v_1 e + v_2 e^2$ is the quadratic daily cost function. Let e_{max} be the maximum e that can be produced in a day. The seasonal profit function is

$$A(X, e, d) = dB(X, e) - FC \qquad (2)$$

where FC is the annual fixed cost. Let D_{max} be the maximum possible number of days fished. Further assume that stock growth is represented by the Schaefer (1954) function

$$G(X) = rX(1-X/K) \qquad (3)$$

K is the maximum stock size, and r is the intrinsic growth rate. The following parameters values will be used in the graphical analysis: P= \$17, q= .00005, v_1=5, v_2=5, e_{max}= 3.2, D_{max}=50, FC=\$3000, r=.3, and K = 100,000.

Vessel Activity Subject to technical constraints, daily profits are maximized where the first derivative of (1) equals zero. Therefore the operational level of e will be:

$$\begin{aligned} e^*(X) &= e_{max} && \text{if } (PqX-v_1)/2v_2 \geq e_{max} \\ e^*(X) &= (PqX-v_1)/2v_2 && \text{if } 0<(PqX-v_1)/2v_2 < e_{max} \\ e^*(X) &= 0 && \text{if } (PqX-v_1)/2v_2 \leq 0 \end{aligned} \qquad (4)$$

The stock size at which $e^*(X)$ falls to zero is important because it is the upper limit on a range of stock sizes where commercial activity will cease. Call this stock size the cushion stock size, X_{cush}, because it is a cushion that bounces the fishery time path back up when the stock falls into this range. See below

$$X_{cush} = v_1/Pq \qquad (5)$$

The profit maximizing vessel will always choose to operate the maximum number of days possible as long as daily profit is positive. Therefore

$$\begin{aligned} d &= D_{max} && \text{if } X > X_{cush} \\ d &= 0 && \text{if } X \leq X_{cush} \end{aligned} \qquad (6)$$

Given the functions for e and d, total annual vessel effort, E, is

$$E(X) = de^*(X) \qquad (7)$$

The stock size where long run vessel profits equal zero when d = D_{max} is the economic equilibrium stock size, X_{be}. It will occur at the combination of X and e where both $\partial B/\partial e$ and $A(X,e, D_{max})$ equal zero.

$$PqX - v_1 - 2v_2 e = 0 \qquad (8)$$

$$PqXe - v_1 e - v_2 e^2 - FC/D_{max} = 0 \qquad (9)$$

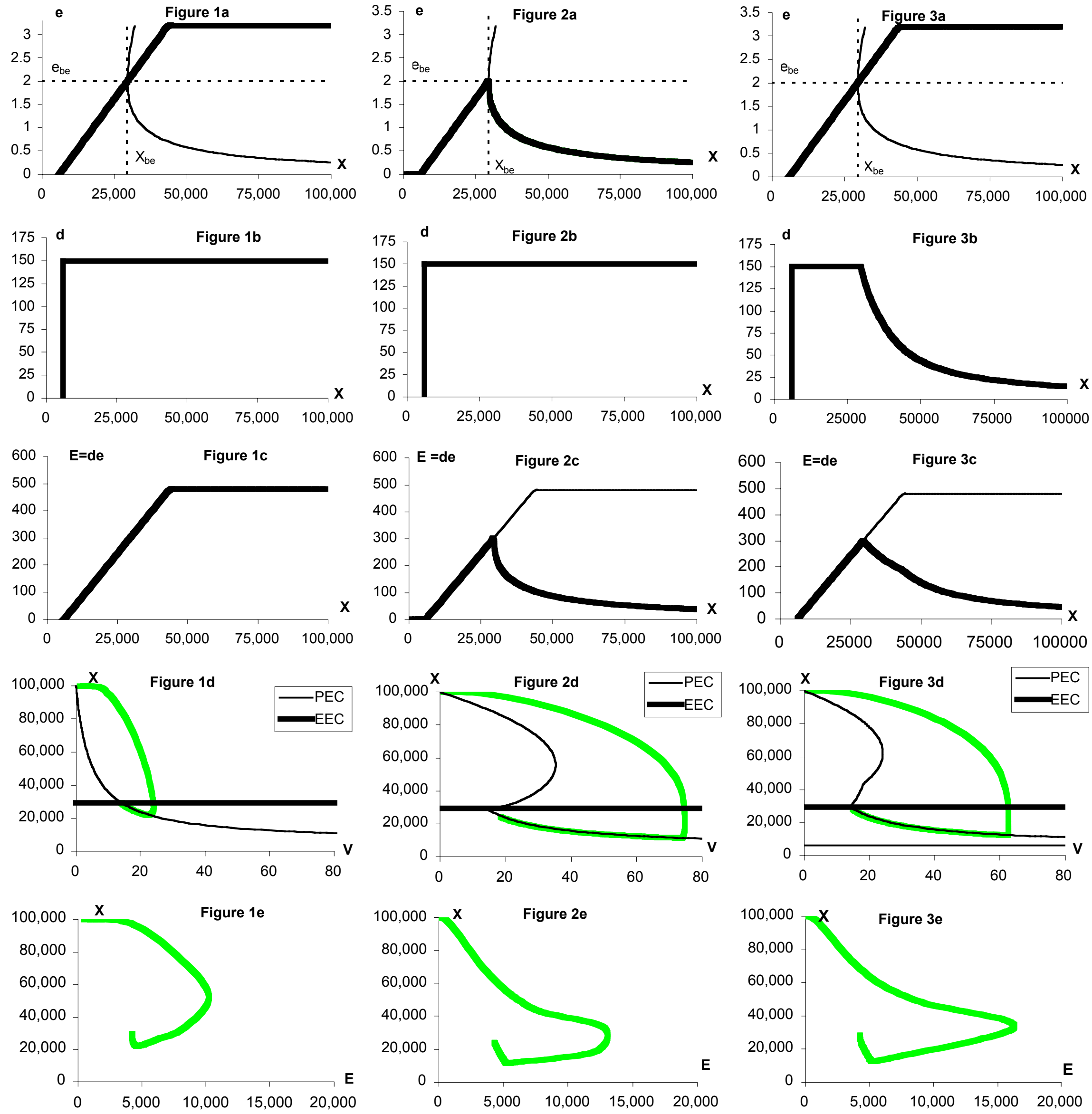
Dividing (9) by e, subtracting it from (8) and solving for e obtains

$$e_{be} = [FC/(v_2 D_{max})]^{1/2} \qquad (10)$$

Substituting this back into (9) and solving for X obtains:

$$X_{be} = [v_1 + v_2\, e_{be} + FC/(e_{be} D_{max})]/Pq \qquad (11)$$

Vessel activity can be summarized in the relationships between X and the variables e, d, and E as pictured in figures 1a, 1b, and 1c respectively. As stated above, after a point both daily and total annual vessel effort will decrease with stock size and will fall to zero at a positive stock size. It is shown below, that depending upon the operational rules used to achieve the profit goal, these patterns will differ and this will have interesting effects on fishery operation.



Figures 1,2, and 3. Vessel and Fishery Behavior under PMB and PGB with Operating Rules 1 and 2.

For purposes of the discussion below, consider a geometric interpretation of the solution of e_{be} and X_{be} in figure 1a. The solid thick curve is the operational e curve based on (4). The solid thin line shows the two solutions of equation (9) for e at the relevant levels of X. Call it the Zero Profit Curve. Only the portion below e_{max} is pictured. Because it will be part of the analysis of operational rules, call the smaller of the two solutions $e_{min}(X)$. The Zero Profit Curve shows the relevant combinations of X and e where daily net returns will exactly cover fixed costs if $d = D_{max}$. All combinations of X and e above and to the right of the curve will produce net returns higher than fixed costs. These represent the combinations where it is theoretically possible to achieve the profit goal. All combinations to the left and below the curve will produce net returns less than fixed costs even when $d = D_{max}$. The operational e curve represents the combinations of X and e where daily profits are maximized. The point where it intersects the Zero Profit Curve represents the combination of X and e where the highest possible daily profit will just cover fixed cost when $d = D_{max}$. This is the economic equilibrium stock size. Two things that follow from this graph will be useful in interpreting analogous graphs with PGB. First, anytime the operational e curve, which can be different than $e^*(X)$, is inside the Zero Profit Curve, it is possible to achieve the profit goal. Second, the point of intersection between the operational e curve and the Zero Profit Curve will determine the economic equilibrium stock size, which can be different than X_{be}.

Bioeconomic Equilibrium A fishery will be in a bioeconomic equilibrium when catch is equal to growth and so stock size will not change, and simultaneously, long run profits are equal to zero and so there will be no tendency for vessel entry or exit. This point can be identified in (fleet, stock) space by plotting the economic equilibrium curve (EEC) and the population equilibrium curve (PEC). See Smith (1969), Anderson (1986, chapter 4) and Hannesson (1993, chapter 2). The EEC is the collection of fleet and stock combinations where long run profit is equal to zero. All points above the EEC represent combinations of X and V where long run profits are positive and fleet size will increase. The reverse holds true for all points below the curve. Since there is only one stock size where long run profits will be equal zero, the EEC will be a horizontal line at X_{be}. See equation (11). The population equilibrium curve shows the combinations of stock and fleet sizes where catch will equal growth. An equation for this curve can be obtained by equating stock growth and total fleet catch and solving for V, the number of vessels is the fleet.

$$G(X) = VdeqX$$
$$V = G(X)/deqX \qquad (12)$$

Substituting in equations (3), (6), and (7) and simplifying obtains.

$$V = [r(1\text{-}X/K)]/[D_{max}qe^{*}(X)] \qquad (12a)$$

As X decreases from K to X_{cush}, the numerator will increase and the denominator will decrease, which means that V will vary inversely with stock size and will approach infinity as X approaches X_{cush} from above. Because effort per boat decreases with stock size, it takes more vessels to harvest the growth even as stock size falls. All points to the left and below the PEC represent combinations of X and V where growth is greater than catch and stock size will increase. The reverse holds true for all points to the right or above it. The intersection of the EEC and the PEC determines the bioeconomic equilibrium. See figure 1d.

The Time Path of the Fishery The time path of the fishery is found by tracing the annual changes in stock and fleet size. Stock size changes according to the difference between growth and catch. The stock size difference equation is:

$$X_{t+1} = X_t + G(X) - V_t d_t e_t q X_t \qquad (13)$$

Substituting in equations (3), (6), and (7) obtains.

$$X_{t+1} = X_t + rX_t(1\text{-}X_t/K) - V_t D_{max} q X_t e^{*}(X_t) \qquad (13a)$$

Following Smith (1969), the change in fleet size will be proportional to long run vessel profits. The vessel difference equation is:

$$V_{t+1} = V_t + M[D_{max}B(e^{*}(X_t),X_t) - FC] \qquad (14)$$

The parameter M is the entry/exit coefficient. For the graphical demonstration it is set equal to .00028.

The PEC, the EEC, and the time path of fleet and stock size for PMB, given the parameters values noted above, are pictured in figure 1d. After an "open access overshoot" the path makes a non-cyclical approach to the equilibrium. In fact, once the time path approaches the PEC, it follows it very closely to the equilibrium point. It is slightly below it and growth is greater than catch and so stock size is growing. It is interesting to note that if the time path is derived assuming that vessels have no control of e and instead produce a constant amount equal to e_{be}, there will be a cyclical path which goes around the equilibrium point in decreasing circles until it is finally achieved. The reason for the non-cyclical path in this case is the way vessels adjust e with changes in X. Figure 1e plots the time path in terms of aggregate effort, VE. It can be seen that while fleet size continues to increase when X is greater than X_{be}, aggregate effort begins to fall at a higher stock size. The decreasing E per boat has a stronger influence than does the increase in fleet size. As the time path approaches the equilibrium, aggregate effort remains fairly constant because of an apparent balancing of increases in E and decreases in V. In effect, the changes in E moderate and compensate for the changes in fleet size and there is a smooth approach to the equilibrium.

3. Introducing Profit Goal Achievement into the Bioeconomic Model.

Since for any X, there are many combinations of e and d that cause net returns to equal FC, what operational rules can vessel operators use to choose a particular combination? The following will be considered here.

- Case 1 Set d equal to D_{max} and vary e.
- Case 2 Set e equal to $e^*(X)$ and vary d.
- Case 3 Set e to a fixed level and vary d.
- Case 4 Set daily catch, y, to a fixed level, then set e to obtain that catch and then vary d.

Case 1 might be selected if there was a desire to spread the harvest throughout the season while Case 2 might be chosen if increasing leisure time were a secondary goal. Cases 1 and 2 are similar in that they each choose one of the two control variables according to PMB. See below. As a result, the economic equilibrium stock size, and ultimately the bioeconomic equilibrium will be the same as with PMB. Cases 3 or 4 would apply if daily trips are defined in terms of effort or catch because of custom or vessel characteristics. In these cases, except for a special case, there will be a different bioeconomic equilibrium. The cushion stock size will always be different

One important aspect of PGB is that stock conditions and limitations on vessel operation can prevent the goal from being achieved. Using Case 1 as an example, at stock sizes below X_{be}, it is not possible to find a level of e that will cover fixed costs even if the boats fishes the full season. What will the vessel operator do in those cases? While there may be situations where vessel operators do not know how or do not care to maximize profits and instead use PGB, it is hard to imagine that they are not able, or do not find it desirable, to compare revenue and costs from daily trips. It is unlikely they will stick to an operational rule when daily net returns are negative. In case 1, the rule for choosing e does not apply when X is less than X_{be} because mathematically the solution is an imaginary number. Therefore assume that the vessel will choose $e^*(X)$, which will maximize daily profits. In cases 2, 3, and 4, the choice rule for e will apply at all stock sizes, but it will not always be possible to achieve the profit goal. In these cases, it will be assumed that operators maintain the choice rule for e, but will stop operating only when daily net returns fall to zero. For case 2, the stock size where this occurs will be the same as with PGB, but in cases 3 and 4, it will vary with the selected constant level of e or y.

The traditional model assumes that vessel exit and entry is proportional to long run profits. Given the assumptions in the previous paragraph, this formulation will still work when $X<X_{be}$ (i.e., when there is vessel exit) because vessels will be earning net returns less than FC. However, when $X>X_{be}$, long run profits will always be equal to zero because the profit goal will be achieved. Therefore in order to model PGB, it is necessary to formulate a vessel entry function. A possible hypothesis is that the rate of entry is proportional to the ease of meeting the profit goal as measured by $[e_{max}–e(X)]$ in case 1 and $[D_{max}–d(X)]$ in cases 2, 3, and 4. However, using such a rule will make it difficult to compare the results of various operational rules with PMB. Because the above values are directly related to the size of potential long run profits that could be earned at any stock size, it will be assumed that entry is proportional to these potential profits. This will generate the same number of entrants at any stock as in the profit maximizing case. However, it will not generate the same time

	Case 1	Case 2	Case 3	Case 4
Daily effort	$e_{c1}(X) = e_{min}(X)$ if $X > X_{be}$ $e_{c1}(X) = e^*(X)$ if $X \leq X_{be}$	$e_{c2}(X) = e^*(X)$	$e_{c3} = e_{fixed}$ $e_{min}(X) < e_{fixed} \leq e_{max}$	$e_{c4}(X)=$ $Min[y_{fixed}/qX, e_{max}]$ $e_{min}(K)qKy_{fixed} \leq e_{max}qK$
Equilibrium X (EEC)	$X_{be(c1)} = X_{be}$	$X_{be(c2)} = X_{be}$	$X_{be(c3)}=$ $[v_1+v_2e_{c3}+FC/e_{c3}D_{max}]/Pq$	$X_{be(c4)}=[-b+(b^2-4ac)^{1/2}]/2a$ $a=Py_{c4}-FC/D_{max}$ $b= v_1(y_{c4}/q)$ $c= v_2(y_{c4}/q)^2$
Cushion X	$X_{cush(c1)} = X_{cush}$	$X_{cush(c2)} = X_{cush}$	$X_{cush(c3)} = [v_1 + v_2e_{c3}]/ Pq$	$X_{cush(c4)}=$ $[-b+(b^2-4a_1c)^{1/2}]/2a_1$ $a_1 = Py_{c4}$
Days Fished	$d_{ci} = Min\{FC/B[e_{ci},X],D_{max}\}$ if $X > X_{cush(ci)}$ $d_{c2} = 0$ if $X \leq X_{cush(ci)}$			
E	$E_{ci} = d_{ci}e_{ci}$			
PEC	$V = G(X)/d_{ci}e_{ci}qX$			
X difference equation	$X_{t+1} = X_t + G(X) - V_td_{ci(t)}e_{ci(t)}qX_t$			

V difference equation	$V_{t+1} = V_t + M[D_{max}B(e^*(X_t),X_t) - FC]$	When $X > X_{be(ci)}$
	$V_{t+1} = V_t + M[d_{ci}B(e_{ci}, X_t) - FC]$	When $X \leq X_{be(ci)}$

Table 1 The bioeconomic model equations for the different operational rules.

path because the stock difference equation will be based on different values of e and d. Since the same number of vessels will produce less aggregate effort with PGB, the rate of stock decline will be lower. The length of time where conditions for entry are favorable will be longer. Because of the caveats on the entry function, the results below should be interpreted with care. Some sensitivity analysis will be performed, however.

The bioeconomic model consists of equations (4), (6), and (7), the operational levels of e, d, and E; equations (5) and (11), the economic equilibrium and the cushion stock sizes; equation (12), the PEC; and equations (13) and (14), the difference equations for stock and fleet size. Given the extra assumptions concerning how the e and d functions change when the profit goal can not be met and on the nature of the exit/entry function, it is a simple matter to apply the basic bioeconomic model to each of the operational rules. Once the operational rule for e_{ci} is specified, where the subscript refers to the case number, it is possible to calculate the values of $X_{be(ci)}$ and $X_{cush(ci)}$. It is then possible to construct the other equations by substituting e_{ci}, $X_{be(ci)}$, and $X_{cush(ci)}$ in the appropriate places. The basic form of the other equations will be the same in all cases. See table 1.

Except in a few cases, the results should be obvious by inspection. First, there are constraints on the levels of e and y that can be chosen cases 3 and 4. The lowest e must be greater than $e_{min}(K)$, the effort level where the profit goal is achieved given the boat operates full time when stock size is at its maximum. It may not be higher than $e_{max.}$ The constraints in case 4 are analogous but in terms of output. Second, the solutions for $X_{be(ci)}$ and $X_{cush(ci)}$ are found by setting equation (2) and (1) equal to zero, respectively, when $e = e_{ci}$ and $d = D_{max}$ and solving for X. In case 4, the equations will be quadratic and the appropriate solutions are the positive value provided by the general equation. These solutions will not apply when the amount of e necessary to catch the fixed y at the solution level of X is greater than e_{max}. A solution can be obtained numerically however. See below. Finally, the general equation for d_{ci} applies in case 1 because, by definition, $FC/B[e_{ci},X]$ will equal D_{max}.

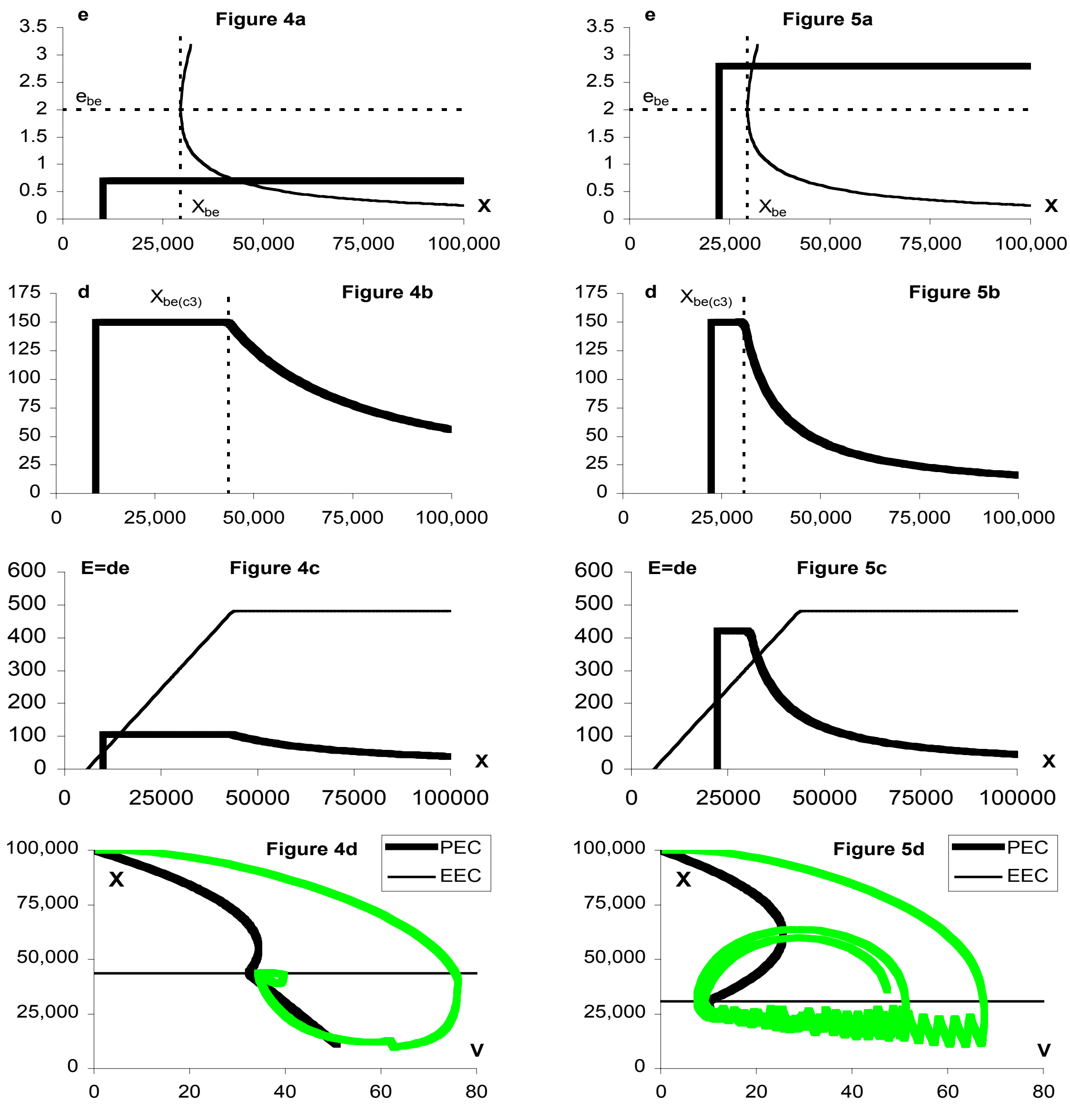
4. Comparisons of Open Access with Profit Maximization and Profit Goal Achievement Behavior.

Comparing and contrasting the various operation rules can be accomplished by constructing a set of graphs analogous to Figure 1. Cases 1 and 2 are pictured in figures 2 and 3. The analysis of cases 3 and 4 can differ depending upon the size of the fixed level of e or y. Figures 4 and 5 picture case 3 with a “low” and a “high” level of e. . Figures 6 and 7 picture case 4 with a “low” and a “high” level of y. To save space, the graph for the time path in terms of aggregate effort is omitted from these figures because the results are analogous to figures 2e and 3e. As a reference point, the zero profit curve is pictured as a thin line in all “a” graphs, and the operational d function for PMB is pictured as a thin line in all “c” graphs.

Consider first cases 1 and 2 in figures 2 and 3. As X decreases from K to X_{be}, the operational e function in case 1 is the lower half of the zero profit curve, what has been defined as $e_{min}(X)$. Below X_{be}, the operational e function is $e^*(X)$. Daily effort, d, is equal to D_{max} at all stock sizes. In case 2, $e^*(X)$ is the operational e function for all levels of X. The number of days fished will increase as X decreases because profit per day decreases, and it will reach D_{max} at X_{be}. In both cases boats will produce less total effort than with PMB for all stock size above X_{be}. See figure 2c and 3c. Below X_{be} boats will produce the same as with PMB. Also note at stock sizes above X_{be}, E will be greater in case 2. This means that with identical stock and fleet sizes, catch will be higher in Case 2 which will have obvious biological effects on the operation of the fishery. This is an artifact of the daily cost function. As daily effort decreases the average cost of effort approaches v_1, and is independent of the total number of days fished. Therefore since case 1 will always have a lower daily effort than will case 2, [$e_{min}(X)$ is less than $e^*(X)$], its cost of effort will be lower and it will take a smaller annual catch to cover fixed costs. This would not necessarily be the case if there were a fixed set up cost included in the daily cost function. Although these are hypothetical examples, the point (which is confirmed in cases 3 and 4) is that different operational rules for achieving the same profit goal will have different effects on annual harvest levels.

Given the differences in the operational E functions in these two cases, the PECs are different as well. See figures 2d and 3d. Over the range from K to X_{be}, the PEC is concave to the stock size axis. When stock size is less than X_{be}, in both cases the PEC is identical to the PEC for the PMB case because vessels change over to PMB in this range. The reason for the backward bending portion of the PEC where fewer boats are necessary to harvest the growth as stock size decreases is that each boat will be producing more effort. Depending on the parameter values, this can occur whether growth is increasing or decreasing as stock size decreases. As noted by Hannesson (1993), if the EEC intersects the PEC in a backward bending region, it will produce an unstable equilibrium. In these two cases, the EEC intersects the PEC at the cusp point where it switches from a backward bending curve to a negatively sloped curve.

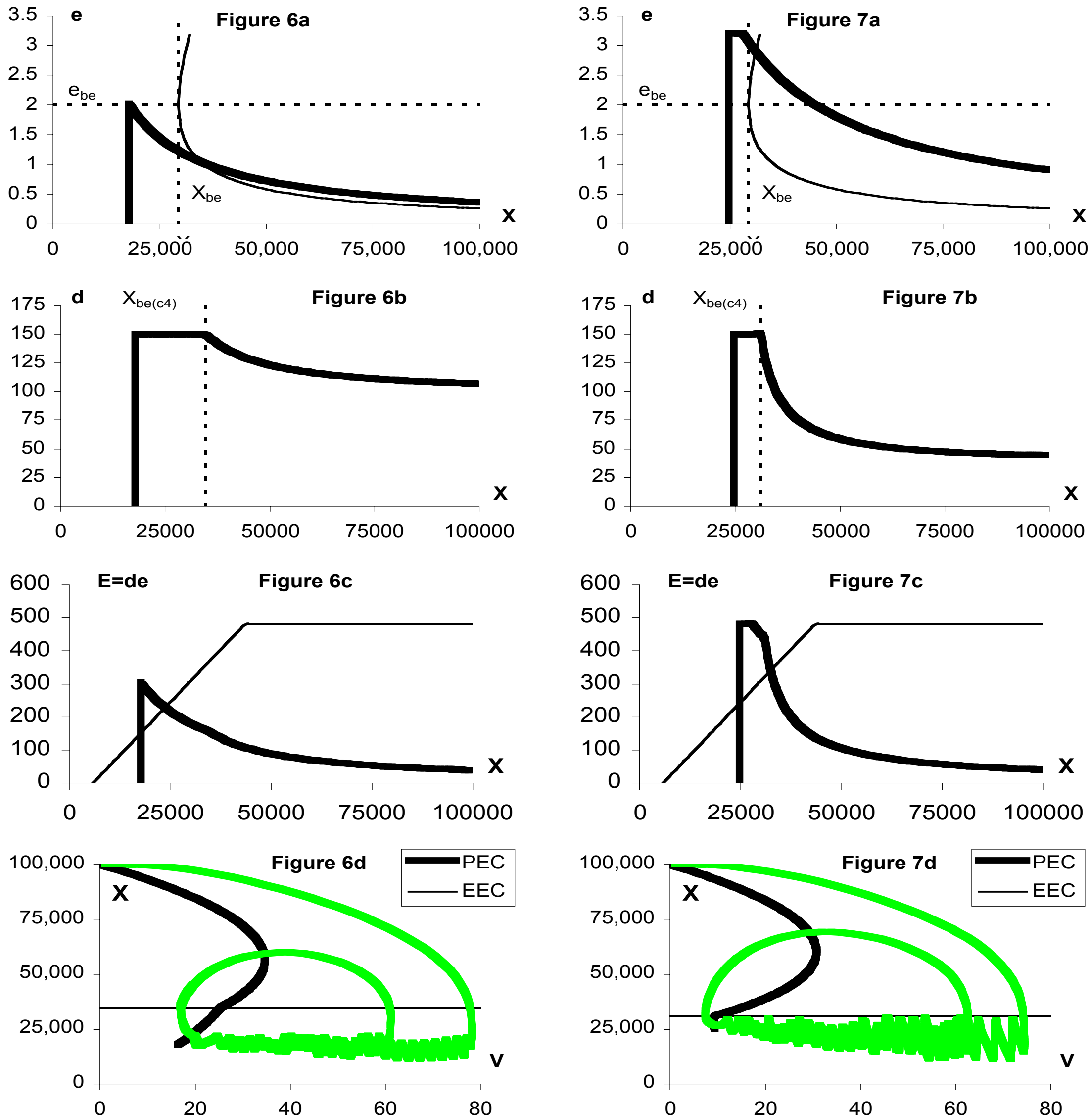
The time path is also presented in figures 2d and 3d, and while its shape must be interpreted with care, there is a larger overshoot with PGB than with PMB. This reason for this is that with otherwise identical vessels producing smaller amounts of effort, the stock will able to support more of them for a longer period of time before it is reduced to X_{be}. The entry function allows the same number of vessels to enter at any stock size for both PMB and PGB. However, even when the entering number of vessels for PGB is reduced to 10% of the PMB amount, there is still a significantly larger overshoot. This conclusion holds for all four cases. Note however, the once the stock falls below X_{be} and PGB becomes the same as PMB, the time path follows the PEC back to the equilibrium point. Figures 2e and 3e show the time path in terms of aggregate effort. At higher stock sizes, aggregate effort is lower than with PGB. However, as the stock continues to decrease the inequality is reversed. Also aggregate effort continues to increase until stock fall to X_{be} which does not occur with PMB. If the comparative values for stock size were plotted against time it would show that while PMB results in a faster decline in X, it does not fall as far and it returns to the equilibrium stock size faster than does PGB.



Figures 4 and 5: Vessel and Fishing Behavior with "Low" and "High" Fixed Values of e for Operational Rule 3.

Consider now case 3 where vessels set a constant e and modify the number of days fished in order to achieve the profit goal. Figure 4 and 5 depict cases where the fixed e is below and above e_{be}, the level of daily effort at the bioeconomic equilibrium with PMB. As noted above, the economic equilibrium stock size, $X_{be(c3)}$ in this case, occurs where the operational e curve intersects the zero profit line. In both of these cases, this occurs at a stock size greater than X_{be}, the economic equilibrium stock size with PMB. See the top two graphs in each figure. It follows, that as the fixed e is increased $X_{be(c3)}$ will initially increase but after e reaches e_{be} further increases will cause $X_{be(c3)}$ to fall. However, the size of $X_{cush(c3)}$ will fall continuously with increases in the level of fixed e.

Again, d will increase with decreases in X and will reach D_{max} at $X_{be(c3)}$. Given that e is already fixed, this means that total effort per boat, E, will initially increase with decreases in X, but will remain constant over the range between $X_{cush(c3)}$ and $X_{be(c3)}$. See Figures 4c and 5c. There are some interesting aspects of the operational d curves that have significant effects on fishery operation. First, while E will be less than the comparative PMB amount at higher stock sizes, at lower stock sizes there is a range where PGB vessels will produce more effort although they will stop operating at a higher stock size. Second, at higher levels of the fixed e, the constant amount of E will be higher but it will be produced over a smaller range of stock sizes. That is, the difference between $X_{cush(c3)}$ and $X_{be(c3)}$ will decrease.



Figures 6 and 7: Vessel and Fishing Behavior with "Low" and "High" Fixed Values of y for Operational Rule 4.

Because of these two points, there are important differences in the shape of the PEC. See figures 4d and 5d. In both situations, the PEC will be concave to the stock size axis over the range between K and $X_{be(c3)}$. Below $X_{be(c3)}$ it will be linear and negatively sloped. See equation (12a) where the denominator is a constant over this range of X. By comparing the two graphs, it can be seen that while the EEC intersects the PEC at its cusp, with a higher fixed e, the concavity of the PEC is more pronounced and the length of the linear portion is reduced, (and partially hidden by the time path. Given the parameter values used in this example, this has an effect on the time path and the stability of the equilibrium. With the lower e, the time path, for the most part, stays above $X_{cush(c3)}$. There is one point where there is an abrupt increase in stock size caused by the fact that vessels shut down because X became less than $X_{cush(c3)}$. In the neighborhood of the equilibrium, the forces implied by the EEC and the PEC are able to push the path to the equilibrium point. The time path for the higher level of fixed e is much different. First given the smaller difference between $X_{cush(c3)}$ and $X_{be(c3)}$, the time path frequently falls below $X_{cush(c3)}$ which explains it saw-tooth shape. While the cushion does prevent the stock from falling further, the fishing industry is affected by periodic shut downs. Also given the short length of the PEC below $X_{be(c3)}$, the time path does not go through the equilibrium point. The fishery has an unstable equilibrium and while the stock is protected by $X_{cush(c3),}$ there will be a continuous pattern of boom and bust and during the bust, not only will the fleet size be falling, but periodically it will not be profitable to fish at all. The instability remains even with reductions in the number of boats that will enter at any stock size.

The results of case 4 where vessels set a fixed daily catch are depicted in figures 6 and 7. The operational e curve increases with decreases in X because it takes more effort to maintain the fixed y with lower stock sizes. Again, the economic equilibrium stock size, ($X_{be(c4)}$ in this case), will occur it intersects the equal profit curve. Figure 6 depicts a case where y is "low" such that e is less than e_{be} at X_{be} and it never reaches e_{max}. In contrast, in figure 7 y is "high" and e is greater than e_{be} at X_{be} and it does get as high as e_{max}. Note that it does so to left of the point where it intersects the zero profit curve. It can be seen that as the fixed y is increased, $X_{be(c4)}$ will initially increase until it reaches X_{be} and then it will fall. At the fixed level of y where the operational e curve intersects the zero profit curve at e_{max}, the fixed y operational rule becomes equivalent to the fixed e rule with e equal to e_{max} and further increases in y will no longer affect $X_{be(c4).}$ Note that the operational e curve in figure 7a increases monotonically until the cushion stock size is reached and production activity will cease. If the fixed level of y were to increase by a small amount, the curve would shift up and the cushion stock size would increase. The highest possible cushion stock size occurs at that level of y where the operational level of e equals e_{max} at $X_{cush(c4)}$. Further increases in y will no longer affect the size of $X_{cush(c4)}$.

Figures 6c and 7c provide a comparison with the E curves for case 4 with PMB. As in case 3, boats will produce less total effort at higher stock sizes, but over a certain range of low stock sizes they will produce more. They will stop operating at a higher stock size. An important difference is that for lower fixed levels of y, the E curve will be monotonically increasing. While d will reach D_{max} at $X_{be(c4)}$, e will continue to increase. With higher fixed levels of y, there is a range of X where E will be constant because both e and d reach their constraint levels. These differences will show up in the shape of the PEC. In Figure 6, it is concave to the stock size origin throughout its range. In figure 7 the concavity of the PEC is over the range between K to the level of X where E becomes a constant. It then becomes a negative linear line. However, because of the decreasing difference between $X_{cush(c4)}$ and $X_{be(c4)}$ with increases in the fixed y, this segment can be quite short. Again the EEC will intersect the PEC at $X_{be(c3)}$ where d first equals D_{max}. In both cases this is still a cusp point because the rate of increase in E changes. The number of operating days can no long be increased and all of the change in E comes from changes in daily effort. The point is that the PEC is still backward bending at the point of intersection with the EEC and a stable equilibrium will never be possible. If the operational e curve hits e_{max} before it intersects the Zero Profit Curve, the analysis becomes the same as in figure 5 where there is a high level of fixed e. The time paths demonstrate the larger overshoot and show that the fishery will go through a continuous cycle of boom and bust at both levels of fixed y.

5. Other Issues Related to Profit Goal Achievement.

Because PGB can potentially produce a larger open access overshoot that will result in larger fleet sizes and smaller stock sizes, to the extent that it is exists the fisheries management problem may well be worse than if operators use PMB. Given the way that both types of operators will function around the equilibrium, it will be necessary to remove more boats or put more strenuous controls on individual behavior. Further the stock rebuilding program may well start at a lower stock size. There are other implications as well. One is the economic inefficiency effect. Not only will there likely be more boats during the development of the fishery, but they will be producing at less than their potential capacity. The economic wastes from open access may be higher than previously thought.

A related point has to do with the current emphasis by FAO and other fisheries organizations with obtaining measures of capacity for existing fisheries as an aid in determining long range management objectives and plans. FAO (1998). Undertaking such studies based on the assumption of PMB will generate incorrect results if PGB is the norm. It is also possible that both types of behavior may be present in the same fishery which could make the problem even more difficult.

While this preliminary analysis has focused on open access operation of a fishery, the implications for the predicted effects of various types of regulation are important as well. For example, if managers try to reduce effort by implementing closed seasons, they may have no or little success if vessel owners use PGB and if their current level of d is less than D_{max}. The regulation will reduce D_{max}, but that may not affect their current choice of the number of days to fish. Similarly, a license limitation program would be less effective than anticipated if operators use PGB, because over certain ranges of stock sizes, vessel effort would increase with decreases in stock size. In both cases, there could be inequities if both types of participants were in the same fishery.

6. Summary and Suggestions for Further Research.

The changes in the basic bioeconomic model which result from substituting PGB for PMB are as follows. Instead of vessel annual effort decreasing with stock size, it will do the reverse at least at stock sizes greater than the economic equilibrium. Depending upon the operational rule used to achieve the profit goal, the inverse relationship between stock size and annual vessel effort can continue even at stock sizes lower than the economic equilibrium. While PGB will result in lower vessel effort at higher stock sizes, depending on the operational rules, it can result in higher vessel effort at lower stock sizes. It can also result in higher economic equilibrium and cushion stock sizes. While this may appear to be biologically beneficial, the bottom line effects depend upon overall fishery operation. Depending upon the determinants of vessel entry with PGB, a topic that was not completely addressed in this paper, it is likely that there will be a larger open access overshoot than with PMB. This means that even with a higher cushion stock size, the stock size may reach lower levels. Because of the way PGB affects the PEC and because of the relatively small differences between the economic equilibrium and cushion stock sizes, the fishery may not be able to reach a stable equilibrium but will instead have a continuous pattern of boom and bust. There may also be periods where the fleet completely stops fishing due to low daily net returns. These results should be interpreted with care because of the caveats concerning the way vessel entry was modeled. Nevertheless, the results are plausible and they were robust over large ranges in the rate of vessel entry.

Among other things, future research on this topic should focus on the fundamental question of whether profit goal behavior is used by participants and, if so, what sort of operational rules are used to implement it. It will also be important to refine the analysis of vessel entry and to expand the open access analysis by considering such things as non-linear production functions, crowding externalities between vessels, a variable price of output, etc.. Finally it will be necessary to provide a rigorous analysis of how profit goal behavior will affect the expected results of common regulation techniques.

7. References

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