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A Study on Impact of Cost Changes in Fishery Using Comparative Static and Dynamic Approach*

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Ⅰ. Introduction

The yield Y in Fishery depends on population size (i.e., fish stock) X, and effort E. Economists think of effort in terms of the boats, men, gear and so on that are required for the fishing activity. This is usually termed nominal effort E, and is calculated by using some standardized

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measure such as vessel-ton-days. Gorden-Schaefer (GS) model use nominal effort, and simple short-run yield equation becomes $Y_t = qX_tE_t$, where $q > 0$ is called a "catchability coefficient".

GS model is a static or an equilibrium model based on the parabolic yield-effort curve. The each point on this curve corresponds to the sustainable yield $Y(E)$, measured, for example, in terms of biomass, resulting from the application of a given level of fishing effort E. If we assume a constant price p per unit of harvested biomass, then the revenue function $TR = pY(E)$ represents the total sustainable revenue resulting from the effort E. In the simplest case the costs of fishing are proportional to the effort expended: $TC = cE$. Where c is the unit cost of effort and is constant.

The difference between total sustained revenue TR and total cost TC is called the sustainable economic rent provided by the fishery resource at each given level of effort E: $TR - TC = pY(E) - cE$. In the open-access fishery effort tends to reach an equilibrium (bioeconomic equilibrium) at the level $E = E_\infty$ at which total revenue TR equals total cost TC. At E_∞, hence, revenue equals cost and net revenue or profit is zero ($TR - TC = 0$). The "zero-profit" condition is, in theory, encountered in all competitive industries, where it is viewed as the healthy outcome of socially desirable competitive forces, This is not the case in an open access fishery. At E_∞ the cost of effort (including compensation to vessel owners and crew) is being covered, but there is nothing left to pay the other important factor, the fish stock. Because access is free, the fish stock is reduced until it is worthless.

The unit cost of effort with TC, c, affects the open access dynamics and bioeconomic optimum. That is, if $E > E_{\infty}$ can be maintained indefinitely, for this would produce a situation in which the total costs of fishing would exceed the total revenues. At least some of the fishermen would lose money and would withdraw from the fishery, reducing the level of effort E. Whereas, if $E > E_{\infty}$ can be maintained indefinitely, because of the open-access condition: at such an effort level the fishermen would earn a profit, additional fishermen would be attracted to the fishery, and effort would increase.

The production function, and the prices of factor inputs, will determine the costs incurred directly by the fishing enterprise. A shift in the production function or a change in factor prices will alter total costs. The costs include fixed costs, variable costs and opportunity costs of labor and capital. Fixed costs are independent of fishing operations (depreciation, administration and insurance costs, etc.), whereas variable costs are incurred when fishers go fishing (fuel, bait, food and beverages, etc.). Opportunity costs are the net benefits that could have been achieved in the next best economic activity, i.e., other regional fisheries, capital investment or alternative employment, and thus must be integrated in cost estimations.

The concept of opportunity cost also has a time dimension, which is especially relevant in the present context. Time is, in a sense, an input into the production function since the harvesting of fish is time-dependent; that is to say, the biomass depends on the length of time it has been allowed to grow. More importantly, time also has an opportunity cost. To appreciate this statement we must realize that the fishery can be treated not only as a renewable resource that produces a stream of net benefits in perpetuity but as an item that can, in principle, be consumed instantly.

I will begin with by outling a simple model. This will constitute the basis with nominal effort for analysis. The effects of cost changes on static equilibrium caused yield, fishing effort and fish stock, are explored. And then, dynamic open access and bioeconomic optimum are analyzed. Thereafter, the basic model is extended to estimate the effects of cost changes through simulations with diminishing returns to nominal effort (Cunningham *et al.*, 1985). The work is briefly summarized in the final section.

Ⅱ. Modeling Approach

This paper is based on the Gorden-Schaefer (GS) model. The fishery production function Y_t, will relate harvest in period t to the fish stock X_t and fishing effort in t, E_t. In general the production function will be written as $Y_t = H(X_t, E_t)$. This production function will be concave, with positive first partial derivatives,[1] non-negative cross partial derivatives,[2] and non-positive second partial derivatives.[3] In this chapter, I use Conrad's model in relation to biological growth function. Also, I shall use nominal effort, and the simple yield equation becomes

1) $\partial H(X_t, E_t)/\partial X_t > 0$, $\partial H(X_t, E_t)/\partial E_t > 0$

2) $\partial^2 H(X_t, E_t)/\partial X_t \partial E_t = \partial^2 H(X_t, E_t)/\partial E_t \partial X_t \geq 0$

3) $\partial^2 H(X_t, E_t)/\partial X_t^2 \leq 0$, $\partial^2 H(X_t, E_t)/\partial E_t^2 \leq 0$

$$Y_t = qX_tE_t \tag{1}$$

$$E_t = \frac{Y_t}{qX_t} \tag{2}$$

The biological growth function is

$$F(X_t) = rX_t\left(\frac{X_t}{k_1} - 1\right)\left(1 - \frac{X_t}{k_2}\right) \tag{3}$$

which we will call the logistic growth function, where $r > 0$ is referred to as the intrinsic growth rate, k_1 is called the minimum viable population size[4] and k_2 indicates the environmental carrying capacity.

The cost function relative to the cost of fishing is given by the simple linear equation

$$C_t = cE_t \tag{4}$$

$$C_t = cY_t/qX_t \tag{5}$$

1. The Static Model of Open Access

In the open-access fishery effort tends to reach an equilibrium at the level $E = E_\infty$ at which total revenue TR equals total cost TC. That is, the revenue and the cost intersect at

4) If the stock were displaced slightly to the left to k_1, net growth would be negative $(F(X_t) < 0)$ and a process leading to extinction would result. Alternatively, if the stock were displaced slightly to the right of k_1, net growth would be positive and the stock would grow toward k_2.

$$\pi = TR - TC = pY(E) - cE = pqXE - cE = 0 \tag{6}$$

To obtain X, E and Y in steady state,

$$X_{\infty} = \frac{c}{pq} \tag{7}$$

$$E_{\infty} = \frac{r}{q}\left[\frac{-c^2}{p^2q^2k_1k_2} + \frac{c}{p}\left(\frac{1}{k_1} + \frac{1}{k_2}\right)\right] \tag{8}$$

Using Equation (7) and (8), we can drive the output

$$Y_{\infty} = \frac{r}{pq}\left[\frac{c^2}{pqk_1} - \frac{c^3}{p^2q^2k_1k_2} + \frac{c^2}{pqk_2} - c\right] \tag{9}$$

Taking the first partial derivatives equation (7), (8) and (9) by c, then

$$\frac{\partial X_{\infty}}{\partial c} = \frac{1}{pq} \tag{10}$$

$$\frac{\partial E_{\infty}}{\partial c} = -\frac{2cr}{p^2q^3k_1k_2} + \frac{r}{pq^2}\left(\frac{1}{k_1} + \frac{1}{k_2}\right) \tag{11}$$

$$\frac{\partial Y_{\infty}}{\partial c} = \frac{r}{pq}\left[\frac{2c}{pqk_1} - \frac{3c^2}{p^2q^2k_1k_2} + \frac{2c}{pqk_2} - 1\right] \tag{12}$$

Stock size in steady state increase as cost rises (equation (10)). Fishing effort in steady state is ambiguous. If we multiplied by $p^2q^3k_1k_2/r$ in equation (11), we can derive $-2c + pq(k_1 + k_2)$, $i.e.$, $\partial E_{\infty}/\partial c$. We decide that

(i) if $\partial E_{\infty}/\partial c > 0$, then $c/pq < (k_1 + k_2)/2$ or $X_{\infty} < (k_1 + k_2)/2$

(ii) if $\partial E_{\infty}/\partial c < 0$, then $c/pq > (k_1 + k_2)/2$ or $X_{\infty} > (k_1 + k_2)/2$

That is, in the case of (i), the effort in steady state will decrease as cost increase. In terms of (ii), the effort in steady state will increase as cost increase. Also, we can know the relationship between yield (i.e., harvest) and cost through equation (12). The term $\partial Y_{\infty}/\partial c$ in equation (12) can rewrite as follows:

$$\frac{\partial Y_{\infty}}{\partial c} = \frac{\partial F}{\partial X_{\infty}} \cdot \frac{\partial X_{\infty}}{\partial c}$$

As we know in equation (10), $\partial X_{\infty}/\partial c$ is positive. The results are alternative that (i)

$$\frac{\partial Y_{\infty}}{\partial c} > 0 \text{ if } \frac{\partial F}{\partial X_{\infty}} > 0 \quad \text{and} \quad \frac{\partial Y_{\infty}}{\partial c} < 0 \text{ if } \frac{\partial F}{\partial X_{\infty}} < 0$$

The level of fishing effort which maximizes rent occurs if marginal revenue is equal to marginal cost. The rent-maximizing level of effort in static open access is identified by finding the point where the revenue curve has a slope of c, the marginal cost of effort and dropping a vertical to the E-axis (Conrad, 1999).

2. The Dynamic Model of Open Access and Bioeconomic Optimum

The dynamic model of open access will consist of two difference equations, one describing the change in the resource when harvested, the other describing the change in fishing effort (Conrad, 1999). The former is related to $X_{t+1} - X_t = F(X_t) - H(X_t, E_t)$. The equation, describing effort dynamics, is more speculative because it seeks to explain the economic behavior of fishers. There are many possible models, but perhaps the simplest and most compelling would hypothesize that effort is adjusted in response to last year's profitability. If the per unit price is $p > 0$ and the per unit cost of effort is $c > 0$, then profit of net revenue in period t may be written as $\Pi_t = pH(X_t, E_t) - cE_t$. If profit in period t is positive we would think that effort in period $t+1$ would be expanded, and if that response were linear we could write $E_{t+1} - E_t = \eta[pH(X_t, E_t) - cE_t]$, then $E_{t+1} = E_t + \eta[pH(X_t, E_t) - cE_t]$. We could write these two difference equations in iterative form as a "dynamical system".

$$X_{t+1} = \left[1 + r\left(\frac{X_t}{k_1} - 1\right)\left(1 - \frac{X_t}{k_2}\right) - qE_t\right]X_t \tag{13}$$

$$E_{t+1} = [1 + \eta(pqX_t - c)]E_t \tag{14}$$

Where $\eta > 0$ is called an adjustment or stiffness parameter.

Taking the first partial derivatives with respect to c_t, we can derive some results:

$$\frac{\partial E_{t+1}}{\partial c_t} = \eta E_t \tag{15}$$

We need to calculate X_{t+2} because E_{t+1} is not derived in X_{t+1}. The term X_{t+2} is

$$\left[1+r\left(\frac{X_{t+1}}{k_1}-1\right)\left(1-\frac{X_{t+1}}{k_2}\right)-qE_{t+1}\right]X_{t+1}$$

Then

$$\frac{\partial X_{t+2}}{\partial c_t} = \frac{\partial X_{t+2}}{\partial E_{t+1}} \cdot \frac{\partial E_{t+1}}{\partial c_t} = -qX_{t+1} \cdot \eta E_t \qquad (16)$$

$$\frac{\partial Y_{t+1}}{\partial c_t} = qX_{t+1} \cdot \frac{\partial E_{t+1}}{\partial c_t} \qquad (17)$$

where $Y_{t+1} = qX_{t+1}E_{t+1}$. Equation (15), (16), and (17) indicate that an increase in the unit cost of effort results in increasing effort and harvest but decreasing stock size.

If a fisherman's objective is the maximization of the discounted present value of profit stream, the static rent maximization is not optimal. Maximizing the present value of net benefits leads to the objective function and subjective function. The method of Lagrange multipliers is a technique for solving constrained dynamic optimization problems (Conrad, 1999). The problem for optimization of net benefits is

$$\begin{aligned} &\text{Max} && \pi = \sum_{t=0}^{\infty}\rho^t \pi(X_t, Y_t) \\ &\text{s.t.} && X_{t+1} - X_t = F(X_t) - Y_t \\ & && X_0 = X^0 \quad \text{given} \end{aligned}$$

where ρ is the discount factor by $\rho = 1/(1+\delta)$, where δ is called the discount rate.

The Lagrangian is

$$L = \sum_{t=0}^{\infty} \rho^t \{\pi(X_t, Y_t) + \rho\lambda_{t+1}[F(X_t) - Y_t + X_t - X_{t+1}]\}$$

where λ is called Lagrange multipliers. In general, every variable defined by a difference equation will have an associated Lagrange multiplier. This means that X_t will be associated with λ_t, X_{t+1} will be associated with λ_{t+1}, and so on. It will turn out that the new variables, λ_t, will have an important economic interpretation. They are also called "shadow prices" because their value indicates the marginal value of an incremental increase in X_t in period t.

The steady-state conditions consist of $X_t = X_{t+1} = X^*$, $Y_t = Y_{t+1} = Y^*$, and $\lambda_t = \lambda_{t+1} = \lambda^*$. The triple (X^*, Y^*, λ^*) is called a steady-state optimum. In steady state we can dispense with all the time subscripts (Conrad, 1999). I derive the first order necessary conditions as follows:

$$\frac{\partial \pi}{\partial Y} = \rho\lambda$$

$$\frac{\partial \pi}{\partial Y} = -\rho\lambda[1-(1+\delta) + F'(X)]$$

$$Y = F(X)$$

Using equation (1) through (5), we can write

$\pi_t = pY_t - \frac{cY_t}{qY_t} = \left[p - \frac{c}{qX_t}\right]Y_t$, which has the partials $\frac{\partial \pi(\cdot)}{\partial X_t} = \frac{cY_t}{qX_t^2}$ and $\frac{\partial \pi(\cdot)}{\partial Y_t} = p - \frac{c}{qX_t}$.

The fundamental equation of renewable resource in the steady-state is expressed as follows:

$$F'(X) + \frac{\partial\pi/\partial X}{\partial\pi/\partial Y} = \delta$$

That is,

$$r\left[2X\left(\frac{1}{k_1}+\frac{1}{k_2}\right) - X^2\left(\frac{3}{k_1k_2}\right)-1\right] + \left[\frac{cr}{pqX-c}\right]\left[X\left(\frac{1}{k_1}+\frac{1}{k_2}\right) - X^2\left(\frac{1}{k_1k_2}\right)-1\right] = \delta \quad (18)$$

$$\frac{3rpq}{k_1k_2}X^3 - \left[\frac{2rc}{k_1k_2} + 2rpq\left(\frac{1}{k_1}+\frac{1}{k_2}\right)\right]X^2 + \left[pq(r+\delta) + rc\left(\frac{1}{k_1}+\frac{1}{k_2}\right)\right]X + c\delta = 0$$

This equation represents that it required the steady state levels of X and Y to equate the resource's own rate of return, (the LHS) to the rate of discount δ. We can drive the optimal stock (X^*), the optimal harvest (Y^*) and effort levels (E^*).

In the Lagrangian expression, the term $\frac{\partial\pi}{\partial Y} = \rho\lambda$ can write $\frac{\partial\pi}{\partial Y} = \rho\lambda = p - \frac{c}{qX_t}$, we get:

$$X = \frac{c}{pq-\rho\lambda q} \quad (19)$$

Taking the first partial derivatives equation (19) by c, then

$$\frac{\partial X^*}{\partial c} = \frac{1}{pq-\rho\lambda q} \quad (20)$$

Using $Y^* = F(X^*)$ in the steady state, we get:

$$\frac{\partial Y^*}{\partial c} = \frac{\partial Y^*}{\partial X} \cdot \frac{\partial X}{\partial c} \tag{21}$$

$$\frac{\partial E^*}{\partial c} = \frac{\partial E^*}{\partial X} \cdot \frac{\partial X}{\partial c} \tag{22}$$

Stock size level in steady state of bioeconomic optimum increase as cost rises, i.e., $\frac{\partial X^*}{\partial c} > 0$ (equation (20)). The level of harvest in steady state of the present value maximization is ambiguous because the term $\frac{\partial X}{\partial c}$ is positive. The results are alternative that $\frac{\partial Y_\infty}{\partial c} > 0$ if $\frac{\partial Y^*}{\partial X_\infty} > 0$ and $\frac{\partial Y_\infty}{\partial c} < 0$ if $\frac{\partial Y^*}{\partial X_\infty} < 0$.

The effort in steady state is ambiguous. Taking the partial derivative of fishing effort (E) with respect to stock size (X), we get:

$$\frac{\partial E}{\partial X} = \left(\frac{1}{k_1} + \frac{1}{k_2}\right)\frac{r}{q} - X\frac{2r}{qk_1k_2} \tag{23}$$

If we multiplied by $\frac{qk_1k_2}{2r}$ in equation (23), we can derive $\frac{k_1k_2}{2r}\left(\frac{1}{k_1} + \frac{1}{k_2}\right) - X$. We decide that

(i) if $\frac{k_1k_2}{2}\left(\frac{1}{k_1} + \frac{1}{k_2}\right) - X > 0$ $\left(\text{i.e., } \frac{\partial E}{\partial X} > 0\right)$, then $\frac{\partial E^*}{\partial c} < 0$

because $\frac{\partial E^*}{\partial X} \cdot \frac{\partial X}{\partial c} < 0$

(ii) if $\frac{k_1k_2}{2}\left(\frac{1}{k_1} + \frac{1}{k_2}\right) - X < 0$ $\left(\text{i.e., } \frac{\partial \text{E}}{\partial \text{X}} < 0\right)$, then $\frac{\partial E^*}{\partial c} > 0$

because $\frac{\partial E^*}{\partial X} \cdot \frac{\partial X}{\partial c} > 0$

That is, in terms of (i), the effort in steady state will decrease as cost increase. In the case of (ii), the effort in steady state will increase as cost increase.

3. An Application : Cunninghams' Model

Biologists, on the other hand, refer to effective fishing effort e. This may be defined as "the fraction of the average population taken by fishing" (Rothschild, 1977). The measurement of e is achieved, however, by considering the proportion of the stock that survives fishing. Precisely, it is "the negative of the natural logarithm of the proportion of fish surviving fishing in a year" (Pope, 1982). Hence if fishing removed 60% of the average population, 40% would survive, giving a e value of $-ln$ (0.4), which is 0.9163. It is argued further that doubling the level of fishing would result in a further 60% of the remaining 40% being captured, giving in e value of 1.8326 (which implies 16% survival overall). Notice however that this argument requires an implicit assumption of diminishing returns to nominal effort: a doubling of the fleet results in less than a doubling of the catch.

From the point of view of nominal effort however, equation (1) is particularly unrealistic, since it implies that there are no diminishing returns to effort. That is, it would mean that if effort were doubled then yield would also double. In the short run, the stock size is more or less given, so that there is an upper limit to yield (Cunningham *et al*, 1985).

Hence, as effort increases so does yield but at a decreasing rate. In other words, diminishing returns to nominal effort occur. One way to show this is to modify our short-run yield equation to

$$Y_t = qX_tE_t^{\alpha}$$

where α represents variable returns to effort. Values of α between 0 and 1 imply diminishing returns and a value of 1 implies the absence of diminishing returns (i.e., nominal effort).

As I mentioned above, as effort increases so does yield but at a decreasing rate. In other words, diminishing returns to nominal effort occur. One way to show this is to modify our short-run yield equation to

$$Y_t = qX_tE_t^{\alpha} \tag{24}$$

$$E_t = \left(\frac{Y_t}{qX_t}\right)^{\frac{1}{\alpha}} \tag{25}$$

1) The Static Model of Open Access

The revenue and the cost intersect at

$$\pi = TR - TC = pqXE^{\alpha} - cE^{\alpha} = 0 \tag{26}$$

$$X_{\infty} = \frac{c}{pq} \tag{27}$$

$$E_{\infty} = \left\{\frac{r}{q}\left[\frac{c}{pqk_1} - \frac{c^2}{p^2q^2k_1k_2} + \frac{c}{pqk_2} - 1\right]\right\}^{\frac{1}{\alpha}} \tag{28}$$

$$Y_{\infty} = \left\{\frac{r}{pq}\left[\frac{c^2}{pqk_1} - \frac{c^3}{p^2q^2k_1k_2} + \frac{c^2}{pqk_2} - c\right]\right\}^{\frac{1}{\alpha}} \tag{29}$$

Taking the first partial derivatives equation (27), (28), and (29), we get

$$\frac{\partial X_\infty}{\partial c} = \frac{1}{pq} \tag{30}$$

$$\frac{\partial E_\infty}{\partial c} = -\frac{2rc^{\frac{2}{\alpha}-1}}{\alpha p^2 q^3 k_1 k_2} + \frac{rc^{\frac{1}{\alpha}-1}}{\alpha p q^2}\left(\frac{1}{k_1}+\frac{1}{k_2}\right) \tag{31}$$

$$\frac{\partial Y_\infty}{\partial c} = \frac{r}{pq}\left[\frac{2c^{\frac{2}{\alpha}-1}}{\alpha pqk_1} - \frac{3c^{\frac{3}{\alpha}-1}}{\alpha p^2 q^2 k_1 k_2} + \frac{2c^{\frac{2}{\alpha}-1}}{\alpha pqk_2} - \frac{c^{\frac{1}{\alpha}-1}}{\alpha}\right] \tag{32}$$

Stock size in steady state increase as cost rises (equation (27)). Fishing effort in steady state is ambiguous.

If we multiplied by $\frac{\alpha p^2 q^3 k_1 k_2}{rc^{\frac{1}{\alpha}-1}}$ in equation (31), we can derive $\frac{-2c^{\frac{2}{\alpha}-1}}{c^{\frac{1}{\alpha}-1}} + pq(k_1+k_2) = -2c^{\frac{1}{\alpha}} + pq(k_1+k_2)$. We decide that

(i) if $-2c^{\frac{1}{\alpha}} + pq(k_1+k_2) > 0$, i.e., $\frac{\partial E_\infty}{\partial c} > 0$, then $\frac{c}{pq} < \frac{k_1+k_2}{2}$,

i.e., $X_\infty < \frac{k_1+k_2}{2}$

(ii) if $-2c^{\frac{1}{\alpha}} + pq(k_1+k_2) < 0$, i.e., $\frac{\partial E_\infty}{\partial c} < 0$, then $\frac{c}{pq} > \frac{k_1+k_2}{2}$,

i.e., $X_\infty > \frac{k_1+k_2}{2}$

That is, in the case of (i), the effort in steady state will decrease as cost increase. In terms of (ii), the effort in steady state will increase as cost increase. The term $\frac{\partial Y_\infty}{\partial c}$ in equation (32) can rewrite as follows: $\frac{\partial Y_\infty}{\partial c} = \frac{\partial F}{\partial X_\infty} \cdot \frac{\partial X_\infty}{\partial c}$. As we know in equation (27), $\frac{\partial X_\infty}{\partial c}$ is positive. The results are alternative that (i) $\frac{\partial Y_\infty}{\partial c} > 0$ if $\frac{\partial F}{\partial X_\infty} > 0$ and $\frac{\partial Y_\infty}{\partial c} < 0$ if $\frac{\partial F}{\partial X_\infty} < 0$.

The rent-maximizing level of effort in static open access is calculated by the same method in the base model.

2) The Dynamic Model of Open Access and Bioeconomic Optimum

We could write two difference equations in iterative form as a "dynamical system".

$$X_{t+1} = \left[1 + rX_t\left(\frac{X_t}{k_1} - 1\right)\left(1 - \frac{X_t}{k_2}\right) - qE_t^\alpha\right]X_t \tag{33}$$

$$E_{t+1}^\alpha = [1 + \eta(pqX_t - c)]E_t^\alpha \tag{34}$$

Taking the first partial derivatives with respect to c_t, we get

$$\frac{\partial E_{t+1}^\alpha}{\partial c_t} = \eta E_t^\alpha \frac{\partial E_{t+1}}{\partial c_t} = \eta E_t \tag{35}$$

This result is the same as in the base model.

$$\frac{\partial X_{t+2}}{\partial c_t} = \frac{\partial X_{t+2}}{\partial E_{t+1}^\alpha} \cdot \frac{\partial E_{t+1}^\alpha}{\partial c_t} = -qX_{t+1} \cdot \eta E_t \tag{36}$$

$$\frac{\partial Y_{t+1}}{\partial c_t} = qX_{t+1} \cdot \frac{\partial E_{t+1}^\alpha}{\partial c_t}, \text{ where } Y_{t+1} = qX_{t+1}E_{t+1}^\alpha \tag{37}$$

Equation (35), (36), and (37) indicate that the cost increase results in increasing effort and harvest but decreasing stock size.

In the case of the present value maximization, we can rewrite harvest function and cost function as follows as: $Y_t = qX_tE_t^{\alpha}$, and $C_t = cE_t^{\alpha}$. The term $\pi_t = pY_t - \frac{c}{(qX_t)^{\frac{1}{\alpha}}} Y_t^{\frac{1}{\alpha}}$, which has the partials $\frac{\partial\pi(\cdot)}{\partial X_t} = \frac{cY_t^{\frac{1}{\alpha}}}{\alpha q^{\frac{1}{\alpha}} X_t^{\frac{\alpha+1}{\alpha}}}$ and $\frac{\partial\pi(\cdot)}{\partial Y_t} = p - \frac{cY_t^{\frac{1}{\alpha}-1}}{\alpha(qX_t)^{\frac{1}{\alpha}}}$. Therefore, the fundamental equation of renewable resource in the steady-state is expressed as follows:

$$r\left[2X\left(\frac{1}{k_1}+\frac{1}{k_2}\right) - X^2\left(\frac{3}{k_1k_2}+\right) - 1\right] + \frac{crk_1k_2\left[-X^3+(k_1+k_2)X^2-k_1k_2\right]^{\alpha}}{\alpha p(k_1k_2)^{\frac{1}{\alpha}-1} q^{\frac{1}{\alpha}} X^{\frac{1}{\alpha}+1} - cr\left[-X^3+(k_1+k_2)X^2-k_1k_2\right]^{\frac{1}{\alpha}-1}} = \delta \tag{38}$$

Using equation (19), (20), and (21), we can also drive the optimal stock X^* and optimal harvest Y^* in the Cunningham's model. In the case of effort E^{α} in steady state, however, we need a different equation. Taking the partial derivative of effort $E^{\alpha*}$ with respect to stock size (X), we get:

$$\frac{\partial E^{\alpha*}}{\partial X} = \frac{1}{\alpha}\left[\frac{r}{q}\left(\frac{1}{k_1}+\frac{1}{k_2}\right)\right]^{\frac{1}{\alpha}} X^{\frac{1}{\alpha}-1} - \frac{2}{\alpha}\left(\frac{r}{qk_1k_2}\right)^{\frac{1}{\alpha}} X^{\frac{2}{\alpha}-1} \tag{39}$$

If we multiplied by $\frac{\alpha}{2}\left(\frac{qk_1k_2}{r}\right)^{\alpha}$ in equation (39), we can derive

$\frac{k_1 k_2}{2}\left(\frac{1}{k_1}+\frac{1}{k_2}\right)X^{\frac{1}{\alpha}-1}-X^{\frac{2}{\alpha}-1}$. We decide that

(i) if $\frac{k_1 k_2}{2}\left(\frac{1}{k_1}+\frac{1}{k_2}\right)X^{\frac{1}{\alpha}-1}-X^{\frac{2}{\alpha}-1}>0$ $\left(\text{i.e., } \frac{\partial E^{\alpha}}{\partial X}>0\right)$,

then $\frac{\partial E^{\alpha *}}{\partial c}<0$ because $\frac{\partial E^{\alpha *}}{\partial X}\cdot\frac{\partial X}{\partial c}<0$

(ii) if $\frac{k_1 k_2}{2}\left(\frac{1}{k_1}+\frac{1}{k_2}\right)X^{\frac{1}{\alpha}-1}-X^{\frac{2}{\alpha}-1}<0$ $\left(\text{i.e., } \frac{\partial E^{\alpha}}{\partial X}<0\right)$,

then $\frac{\partial E^{\alpha *}}{\partial c}>0$ because $\frac{\partial E^{\alpha *}}{\partial X}\cdot\frac{\partial X}{\partial c}>0$

Ⅲ. Simulations and Results

1. The Static Model of Open Access

This study used numerical values to simulate both static open access equilibrium. The real values are as follows as: the unit price $p=1$, the intrinsic growth rate $r=0.1$, the minimum viable population size $k_1=0.1$, the environmental carrying capacity $k_2=1$, the catchability coefficient $q=0.1$, and the unit cost of effort c are 0.03, 0.04, and 0.05 for cost change.

The equilibriums in static open access are the effort of 1.4 in <figure 1 (a)>, 1.8 in <figure 1 (b)>, and 2.0 in <figure 1 (c)>. That is, the effort in steady state goes up as cost increase. This result is related to the (ii) case of equation (12).

In the case of the Cunningham's model with diminishing returns to effort, the equilibriums when $\alpha = 0.87$ and $c = 0.03$ are the effort of 1.747 in <figure 1 (d)>, 2.123 (when $\alpha = 0.87$ and $c = 0.04$) in <figure 1 (e)>, and 2.25 (when $\alpha = 0.87$ and $c = 0.05$) in <figure 1 (f)>. With $\alpha = 0.87$, i.e., there is diminishing returns to effort, the effort in steady state more fastly increase as cost increase compare to the absence of diminishing returns (nominal effort case).

2. The Dynamic Model of Open Access

In the case of open access dynamics and bioeconomic optimum, the real values are based on the following information: the unit price $p = 1$, the intrinsic growth rate $r = 0.1$, the environmental carrying capacity k ($k_1 = 0.1$ and $k_2 = 2$), the catchability coefficient $q = 0.1$, adjustment parameter $\eta = 5$, discount rate $\delta = 0.05$, and the unit cost of effort c are 0.03, 0.05, and 0.07.

This study observed the results between 0.03 and 0.07 as the ranges of the unit cost of effort. These results are illustrated by <figure 2 (a)>~<figure 2 (c)>. The fish stock does not converge to open access equilibrium from 0.03 to 0.05, using an initial value of $X = 0.6$ and $E = 1$. However, as the results of simulations show, when $c = 0.07$, the fish stock has the stability at the value 0.7 as well as effort converges <figure 2 (c)>.

We know that the fish stock increase if unit cost of effort is higher through <figure 2 (a)>~<figure 2 (c)>. In other hand if the unit cost of effort are smaller, the population of fish go to the extinction and effort increase.

With diminishing returns to effort $\alpha = 0.87$ <figure 2 (d)>~<figure 2

(f)>, the fish stock converge to open access equilibrium when $c=0.05$ compare to $c=0.07$ in the base model. The fish stock also increase as the unit cost of effort rises, but the fish stock will be depleted slowly than base model case.

3. Bioeconomic Optimum

In terms of bioeconomic optimum, to solve the bioeconomic optimum, we need more in function relative to fish stock. We assume that the fish stock were estimated to be $X_0=0.03$ and that fishery managers decided to maximizes the present value of net revenues to $t=0, 1, 2, \cdots, 9$, subject to $X_{10}=X^*$. Using the unit cost of effort, from 0.001 to 0.2, the maximizing the present value of net benefit through Excel's solver provides the numerical solution associated with each simulation.

The solutions are represented by <figure 3>. The fish stock shows higher through time if both the unit cost of effort is so low ($c=0.001$) and high ($c=0.2$) by <figure 3 (a)>. When the unit cost of effort is higher, the fishing effort decreases through time (<figure 3 (b)>). Especially, the optimal fishing effort decreases rapidly after the high unit cost of effort, $c=0.2$. The optimal harvest through time is presented in <figure 3 (c)>.

With diminishing returns to effort $\alpha=0.87$, the optimal fish stock paths in each case have similar trend compare to base model (<figure 4 (a)>). The optimal fishing effort decreases as the unit cost of effort rises, but effort does not decrease rapidly in high level of the unit cost of effort (<figure 4 (b)>). The optimal harvest paths are depicted by <figure 4 (c)>.

Ⅳ. Conclusions

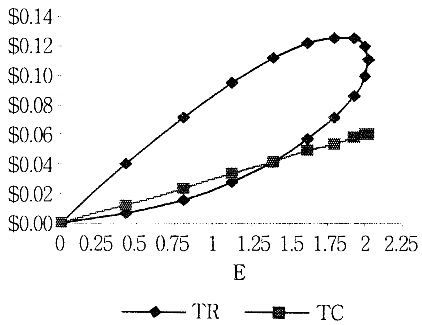
As we analyzed above, the unit cost of effort c affects the level of fish stock. An increase in the unit cost of effort goes up the fish stock in static open access, but open access dynamics shows the exhaustion of fish stock as the unit cost of effort decreases (i.e., below $c = 0.07$). The effort and harvest in static open access equilibrium and dynamic open access equilibrium increase or decrease according to biological conditions. It is analyzed by comparative statics through base model and Cunningham's model.

The extension is more likely if the fishery is characterized by open access and has low unit costs of effort. A possible scenario is as follows. An open access fishery starts out with a sustainable equilibrium, but then technological change lovers the unit costs of effort. In many fisheries there have been large technological change advances that have reduced the cost of harvesting. Examples are the use of sophisticated capital equipment such as sonar. More recently, satellites are being used to track pelagic species, and information about the location of the fish is fed instantaneously to shipboard computers.

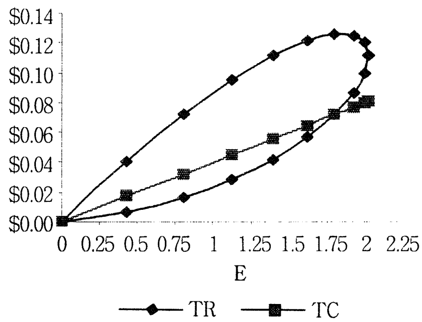
These new techniques may offset the higher marginal harvesting costs that would normally result from a lower stock of fish. Harvesting continues, and the stock is ultimately extinguished. Rising demand for fish may also contribute to extinction of species. Rising incomes can cause demand to increase. The price of fish rises, harvests increase, and the fish population falls. If the demand curve shifts up enough, the open access equilibrium may again occur below the threshold, and the species will become extinct.

〈Figure 1〉 Revenue and Total Curve in Static Open Access

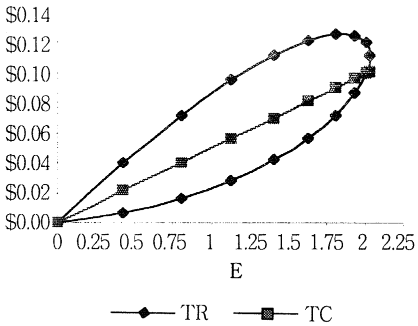
(a) When $c = 0.03$



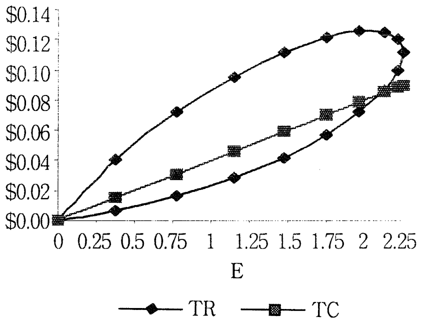
(b) When $c = 0.04$



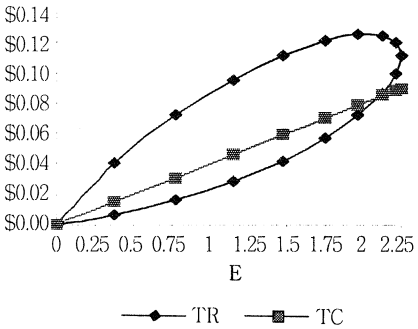
(c) When $c = 0.05$



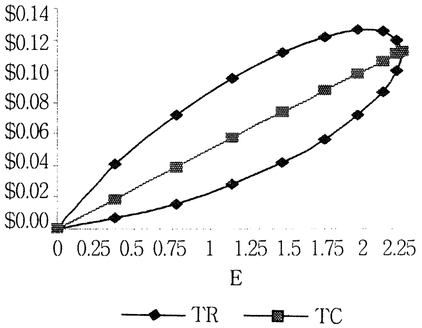
(d) When $c = 0.03,\ \alpha = 0.87$



(e) When $c = 0.04,\ \alpha = 0.87$

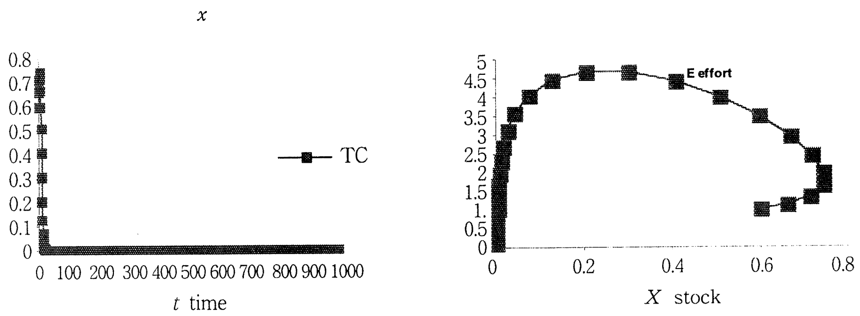


(f) When $c = 0.05,\ \alpha = 0.87$

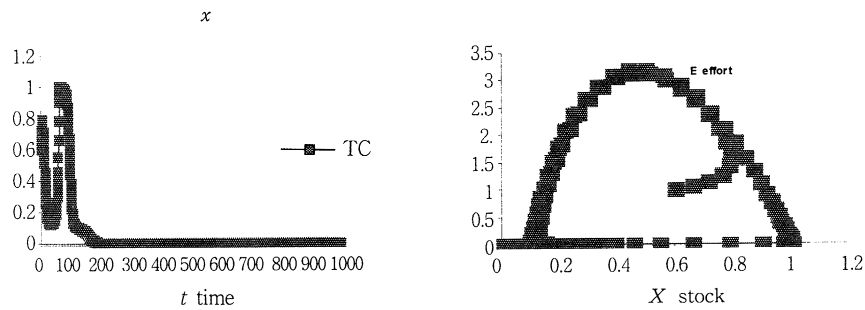


⟨Figure 2⟩ The Cost Effects in Open Access Dynamics

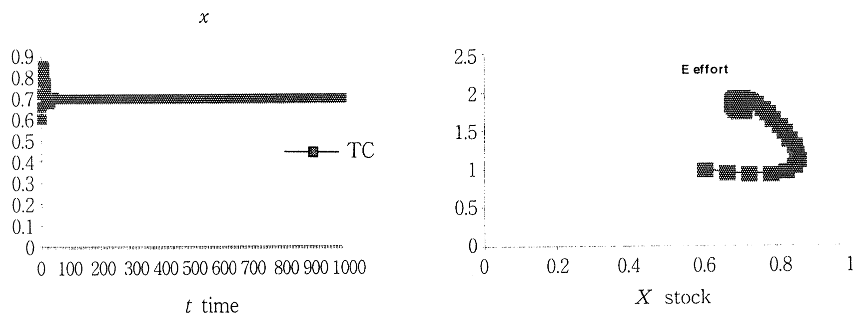
(a) When $c = 0.03$



(b) When $c = 0.05$

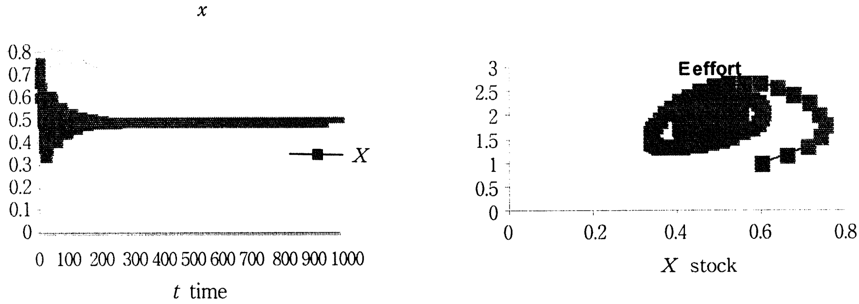


(c) When $c = 0.07$

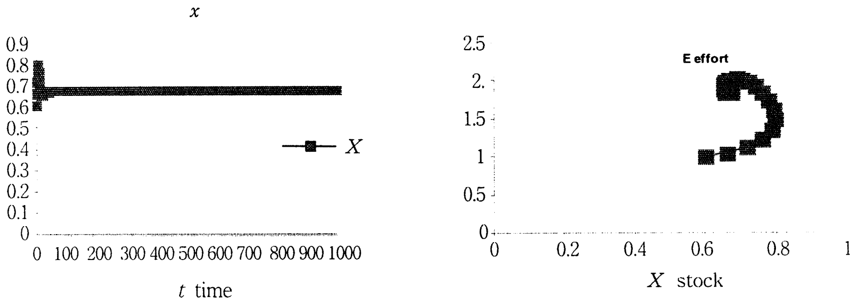


〈Figure 2〉 Continue

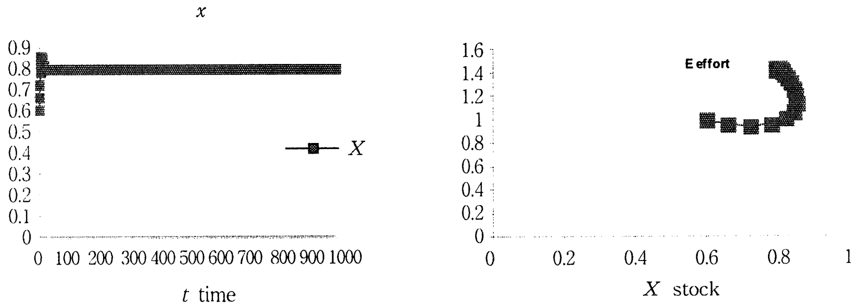
(d) When $c = 0.03$, $\alpha = 0.87$



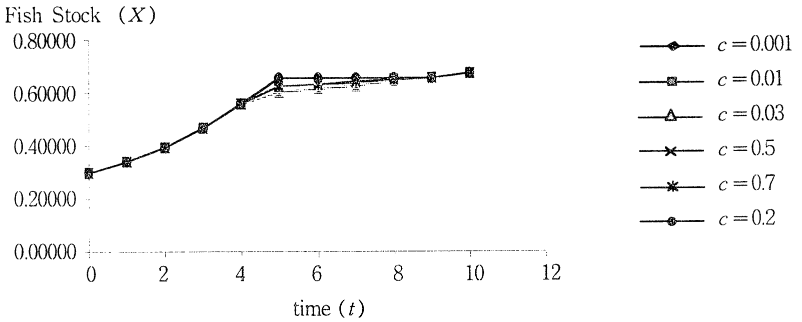
(e) When. $c = 0.05$, $\alpha = 0.87$



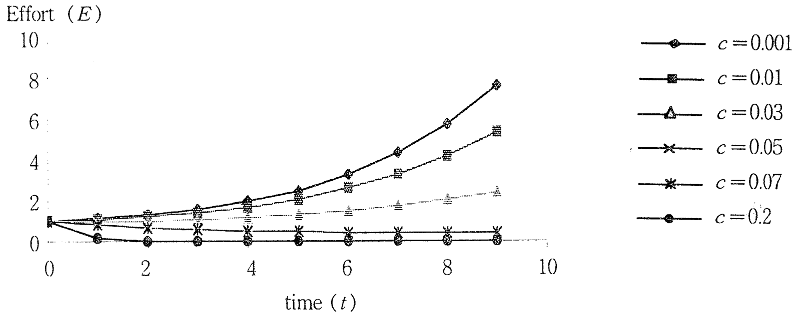
(f) When $c = 0.07$, $\alpha = 0.87$



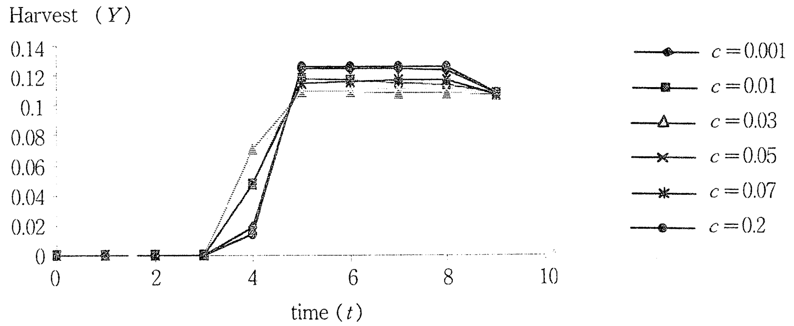
〈Figure 3 (a)〉 The Cost Effects on Fish Stock in Bioeconomic Optimum



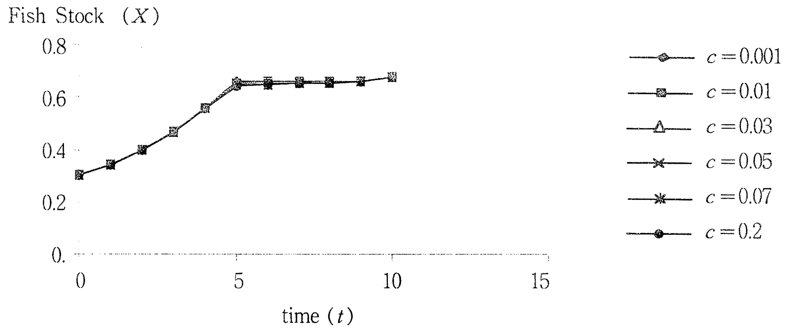
〈Figure 3 (b)〉 The Cost Effects on Effort in Bioeconomic Optimum



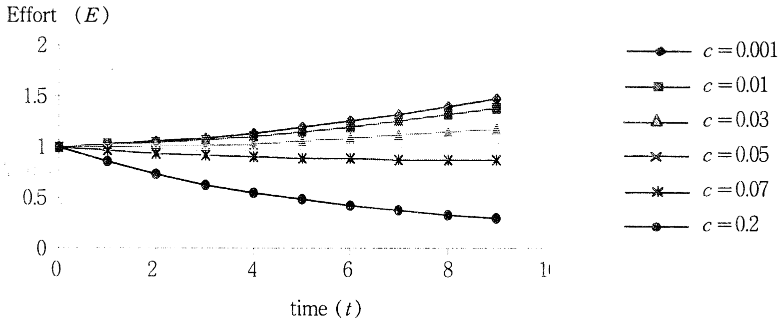
〈Figure 3 (c)〉 The Cost Effects on Harvest in Bioeconomic Optimum



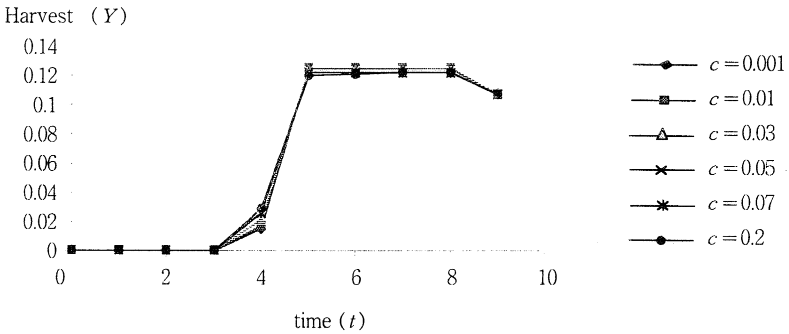
〈Figure 4 (a)〉 The Cost Effects on Fish Stock in Bioeconomic Optimum(α = 0.87)



〈Figure 4 (b)〉 The Cost Effects on Effort in Bioeconomic Optimum(α = 0.87)



〈Figure 4 (c)〉 The Cost Effects on Harvest in Bioeconomic Optimum(α = 0.87)



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A Study on Impact of Cost Changes in Fishery Using Comparative Static and Dynamic Approach

Jong Du Choi

This study uses Conrad's model (nominal fishing effort) of a fishery to analyze theoretically the effects of cost changes on fishing effort, harvest level, and stock size. Static and dynamic open access effects are also modeled present value maximizing scenarios through simulations, and compared an extended model, Cunningham's model (diminishing fishing effort).

Results show that an increase in the unit cost of effort goes up the fish stock in static open access, but open access dynamics shows the exhaustion of fish stock as the unit cost of effort decreases. In conclusion, we can derive the optimal equilibrium of resource, given conditions and parameters, as well as utilize this comparative statics to efficient fishery management.

Key Words : bioeconomic optimum, comparative static and dynamic analysis, cost change

비교 정태·동태 분석을 이용한 수산물 비용변화의 영향에 관한 연구

최 종 두

본 연구는 수산물에 있어서 어획노력비용의 변화가 어획노력, 어획량, 자원들에 실질적으로 어떠한 영향을 미치는 가를 Conrad 모델(명목 어획노력)을 기초로 이론적 접근을 시도하였고, 모의실험을 통하여 실증적인 비용계수의 변화에 따른 정태적·동태적 균형과 생물경제학적 최적(순현재가치)을 도출하였다. 또한 분석의 다양화를 위하여 동일한 방법으로 Cunningham의 모형에서 제시된 체감 어획노력을 이용하여 비용변화에 따른 효과추정을 Conrad의 결과와 비교하여 설명하였다.

어획노력의 단위당 비용의 상승은 수산자원을 증가시킬 수 있지만, "동태적 자유입어" 하에서는 어획노력의 단위당 비용이 감소한다면 수산자원의 고갈을 일으킬 수 있다는 것을 보여주었다. 결론적으로 주어진 조건과 파라메타들을 사용하여 우리는 대상자원에 대한 최적 균형점을 도출할 수 있을 뿐만 아니라 그에 따른 수산자원의 효율적인 관리에 이용할 수 있게 되는 것이다.

핵심용어 : 생물경제학적 최적, 비교정태·동태분석, 비용변화.