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AN EMPIRICAL STUDY OF COMMON PROPERTY RESOURCE: THE CASE OF SKIPJACK FISHERY IN THE WESTERN-CENTRAL PACIFIC OCEAN

by

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Abstract A dynamic Cournot game model is used to predict the strategic behavior of harvesters engaged in a non-cooperative fishery on a common property resource. The model predicts that an increase in the current number of harvesters in a common property fishery will reduce both the equilibrium harvest level and the current resource rent for the individual harvester. Also, an increase in the future number of harvesters increases both two equilibrium levels. These predictions are tested using data from the Japanese skipjack fishery in the Western-central Pacific Ocean. The empirical results on the effect of changes in the current and future numbers of harvesters on the individual harvest rates and resource rent are consistent with theory.

1. Introduction

One of the fundamental insights gained from the analysis of common property resources is that these resources will tend to be over-harvested. The degree of this over-harvesting depends on the number of harvesters. In the case where open access is assumed, over-harvesting results in all rents from resource harvest being dissipated. With a limited number of harvesters, rents are not generally fully dissipated. When resource rents are not fully dissipated, harvesters have a motive for caring about future conditions. Lowering harvest in the present will increase stock levels and resource rents available in the future. In contrast, open-access harvesters have no incentive to behave other than myopically, as they cannot capture future (or present) rents.

In this paper, I develop a simple model of a common property fishery as a dynamic game with an arbitrary number of harvesters. Harvesters are assumed to simultaneously choose harvest levels within a period. Between periods the fish stock grows according to a deterministic growth function. I solve the model for subgame perfect equilibrium. I use the model to develop predictions about the how the number of present and future harvesters affects equilibrium. Specifically, I show that an increase in the current number of harvesters reduces both the current individual harvest and current resource rent. On the other hand, an increase in the future number of harvesters, *ceteris paribus*, increases the individual harvest and the current resource rent. With open-access, however, a change in future conditions has no effect on current equilibrium values, as there is no dynamic link in behavior.

The predictions of the model are tested empirically using data on the skipjack fisheries in the Western-central Pacific Ocean (WCPO). The WCPO includes a high sea and the numbers of islands country's exclusive economic zone (EEZ). The skipjack and tuna stock (highly migratory fish stock) in the WCPO has been harvested by numbers of distant-water fishing (DWF) countries, Japan, USA, South Korea, Taiwan, and Russia, and by numbers of coastal states, Australia, New Zealand, Indonesia, Philippine, and Solomon, since the early 1980's. Most countries have gradually increased their numbers of boats and total harvest of skipjack and tuna from the WCPO. I obtained information on the total number of vessels operating from all countries in this fishery between 1969 and 1999. In addition, from the Japanese Ministry of Agriculture, Forestry and Fishery I obtained detailed information on costs incurred and the revenues earned by the Japanese skipjack fishery fleet operating in this skipjack pole and line fishery between 1972 and 1998.

I tested the predictions of the model using two equations for the current individual equilibrium harvests and individual current profit (resource rent). These equations include the current and future number of harvesters as explanatory variables. The parameters for the two equations are estimated by using equation-by-equation ordinary least squares (OLS). The most estimated parameters for the current and future number of harvesters are of the expected sign in two equations.

There have been a number of prior game-theoretic models of a harvesting from a common-property resource. Levhari and Mirman (1980) first developed a model in which they solved for feedback dynamic equilibria in Cournot and Stackelberg duopoly models. The closest model to one the considered in this paper is Negri (1990). Negri (1990) analyzed a dynamic Cournot model with *n* harvesters where average and marginal harvest cost increases with the ratio of harvest to stock. He solves for a subgame perfect equilibrium in an infinite-horizon model with different numbers of harvesters. He shows that with open access, the equilibrium leads to complete rent dissipation.

Another theory that could be used to explain the dynamics present in a common property resource was developed and analyzed by Smith (1968). Smith (1968) assumed competitive harvesters that ignored the effect that their individual actions had on the resource stock and price. Further, he assumed that the rate of entry (exit) was proportional to the rate of profit (loss). Smith's model can generate similar dynamics in a common property resource to game-theoretic models. One difference, however, is that since harvesters in Smith's model are static optimizers, the number of future harvesters should not affect current equilibrium values.

While there are a number of theoretical models of harvesting a common property resources, there are a few empirical work for a common property resources (e.g., Paterson and Wilen, 1977; Henderson and Tugwell, 1979; Carlos and Lewis, 1993; Missios and Plourde, 1996). These studies, however, analyzed strategic behavior in fisheries without testing game theoretic predictions by econometric technique. Previous empirical work testing game theoretic predictions for resource models have focused on non-common property nonrenewable resources (e.g., Griffin, 1985; Dahl and Yucel, 1991; Polasky, 1992).

This paper is organized as follows. Section 2 presents the background of the international and Japanese skipjack and tuna fisheries in the WCPO. Section 3 provides the two propositions for the strategic behavior of the common property harvesters by using the Cournot dynamic oligopoly model of Negri. Section 4 presents empirical models and estimation techniques. Section 5 explains the data used in this study. In section 6, the results are reported. The final section concludes the paper.

2. Background

According to the Japanese division of water area, the Western-central Pacific Ocean (WCPO) is located at the area between 20°N latitude and 10°S latitude, and between 130°E longitude and 180°W longitude (see Figure 1). The WCPO includes a high sea and the numbers of coastal states' (including many island countries) exclusive economic zone (EEZ). The coastal state countries in the WCPO, Australia, New Zealand, and island countries (Fiji, Kiribati, Federated State of Micronesia, Papua New Guinea, Nauru, Niue, Solomon Island,

and Tubaru) organized the South Pacific Forum of Fisheries Agency (FFA) in 1979. The WCPO overlaps the FFA water area, in the area between 20°N latitude and 25°S latitude, and between 130°E longitude and 150°W longitude (see Figure 1).

The WCPO is the most valuable fishing ground of skipjack and tuna (yellowfin tuna and big eye) for Japanese distant-water fishing (DWF). The skipjack and tuna stocks (highly migratory fish stock) in the WCPO were harvested by only Japanese DWF vessels until 1980. After that, many countries entered into this fishery and gradually increased their number of vessels and total harvest of skipjack and tuna from the WCPO. These fish stocks are generally harvested by using purse seine (purse seine fishery). However, part of the tuna stock is harvested by using long-line and part of the skipjack stock is harvested by using pole and line.

Table 1 shows the numbers of operated vessels (purse seiners) by countries during 1969 through 1999. Japanese purse seiners started to increase the number of vessels since 1974 and maintained around 35 vessels after 1982. This is because Japanese distant-water purse seiners operate under fishing licenses issued by the Japanese government which restricts the number of purse seiners, the size of fishing vessels, and the operating area. The Japanese government could not increase the number of purse seiners because they have to balance between the fish landing from the distant-water and from the Japanese coast.

There are also some other DWF countries operating in the WCPO. The US entered in the WCPO in 1976, and gradually increased the numbers of vessels and reached a peak of 62 vessels in 1983. South Korea and Taiwan started the purse seine fishery in the WCPO in 1980 and 1983, respectively. Their numbers of operated vessels also increased and reached a peak of 39 vessels in 1990 and 45 vessels in 1992, respectively. Other DWF countries, Russia and New Zealand (which is the one of FFA members, but the WCPO water area is far from the New Zealand) entered in the WCPO in 1985 and in 1975 (although the data is missing until 1983), respectively. Mexico once entered the purse seine fishery in 1984, but left in 1986. Spain entered the purse seine fishery in 1999.

A number of coastal states also entered into the WCPO for the purse seine fishery. Those countries include the Philippines, Solomon Island, Federal State of Micronesia, Papua New Guinea, Vanuatu, Australia, Indonesia, and Kiribati, which are mostly members of FFA. The numbers of vessels for those coastal countries are much smaller than the ones of DWF countries (number of one figure).

With the emergence of many new countries, the total number of vessels in the WCPO is obviously growing. The total number of vessels started with only 4 in 1969 and gradually increased to 69 in 1982. The next year, the number doubled (120 vessels). The number gradually increased and reached a peak of 197 in 1992. Since then, the number of vessels has remained fairly constant at around 190. Although there is an international organization such as FFA, the FFA is only for the coastal countries in the South Pacific Ocean. The FFA recently tried to control the fishery in WCPO without DWF countries, but Japan and South

Korea, the DWF countries, opposed it and asserted that international organization managing the fishery in the WCPO should include, not only coastal countries, but also DWF countries. Hence, there is no international agreement for the management of the number of vessels in the WCPO. The skipjack and tuna fishery in the WCPO is, in fact, a so-called "tragedy of commons" situation.

3. Dynamic Cournot Equilibrium Harvest of a Common Property Resource

In this section, I define a two-period model of harvest by an arbitrary number of harvesters from a common property resource. The model is similar to that of Negri (1990) in that within a period harvesters act like Cournot competitors, simultaneously choosing harvest levels, and between periods the resource stock evolves according to a deterministic growth function. Unlike Negri (1990), a different number of harvesters in different periods is allowed. The model is solved for a subgame perfect equilibrium. I derive testable predictions about non-cooperative equilibrium in a common property resource such as the skipjack and tuna fishery in the WCPO.

3. 1 The model

Suppose there are n_t harvesters of the common property resource, denoted $i = 1, 2, \cdots, n_t$, for t = 1, 2. In the beginning of each period, the harvesters face a resource stock S_t. The initial resource stock, S_1, is given. The n_t harvesters simultaneously choose harvest level in period t. Let $h_t^i \geq 0$ represent the harvest level of harvester i in period t and let $H_t = \sum_{i=1}^{n_t} h_t^i$ be total harvest in period t. The total harvest is non-negative and cannot exceed the resource stock ($0 \leq H_t \leq S_t$). The resource stock evolves from period to period according to $S_{t+1} = g(S_t - H_t)$, where g(.) is a deterministic concave growth function.

Further, the unit cost of harvesting fish is assumed to increase with the ratio of harvest to stock. Typically as the stock level falls, it becomes more difficult to harvest fish and unit harvest costs should increase. The cost of harvesting fish, C_t^j, can be written for the n harvesters as

$$C_t^i = \alpha \frac{H_t}{S_t} h_t^i; \qquad i = 1, 2, \cdots, n; \quad t = 1, 2, \tag{1}$$

where α is a cost parameter ($\alpha > 0$).

The profit earned by each harvester i from the fishery in period t, π_t^i, is the difference between the revenue and the cost in each period. The unit price of the harvested fish is assumed to be constant at P (i.e., perfectly elastic demand because there are many substitutes in the world market) with $0 < P < 2$.[1] The profits earned in period t by the n harvesters are

$$\pi_t^i = h_t^i\left(P - \alpha\frac{H_t}{S_t}\right); \qquad i = 1, 2, \cdots, n; \quad t = 1, 2. \tag{2}$$

All n harvesters are assumed to have complete information, that is, the payoff functions (profits) are common knowledge.

To solve the two-period Cournot model for a subgame perfect equilibrium, backwards induction is used and begins in period 2 (i.e., the last period of the game). When period 2 is reached, the n harvesters face the following profit maximization problem:

$$\max_{h_2^i} \quad \pi_2^i(h_2^1, h_2^2, \cdots, h_2^n)$$

$$= \max_{h_2^i} \quad h_2^i\left(P - \alpha\frac{H_2}{S_2}\right); \qquad i = 1, 2, \cdots, n. \tag{3}$$

The first order condition of (3) is set equal to zero to find a typical harvester's best response function.[2] The n identical first-order conditions are summed and solved for the profit maximizing harvest level of all n collective harvesters:

$$H_2^* = \frac{n}{n+1}\frac{P}{\alpha}S_2. \tag{4}$$

Dividing the equation by n, the optimal harvest level for each harvester i is

$$h_2^i = \frac{1}{n+1}\frac{P}{\alpha}S_2; \qquad i = 1, 2, \cdots, n. \tag{5}$$

This equation shows the subgame perfect equilibrium for each harvester in period 2. It is a feedback (subgame perfect) solution and a function of the state of the system in period 2 (i.e., S_2).

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[1] To get an interior solution for the subgame perfect equilibrium in this model, the size of P has to be:

$$0 < P < 2\alpha.$$

This is because if P is greater than or equal to 2α, all harvesters will harvest all stock in the first stage and the game will be over.

[2] The second-order conditions are satisfied for a maximum in both period 1 and 2. In both cases, the second-order conditions are negative:

$$\frac{\partial^2 \pi_t^i}{\partial (h_t^i)^2} = -\frac{2\alpha}{S_t} < 0; \qquad t = 1, 2.$$

There is a unique (stable) equilibrium in both period 1 and 2, as in the standard Cournot model with linear demand and constant returns to scale, because the absolute value of the second derivative of a firm's profit function with respect to its own harvest is greater than the absolute value of the second derivative of the firm's profit function with respect to rivals' harvests (Tirole, pp. 226).

Substituting the subgame perfect equilibrium in (5) and the aggregated equilibrium harvest of all harvesters in (4) into the objective function in (3), the one-period optimal value function for each harvester is

$$V_2^{i*}(S_2) = \frac{1}{(n+1)^2}\frac{P^2}{\alpha}S_2; \qquad i = 1, 2, \cdots, n. \tag{6}$$

Given the second period solutions, the problem for each harvester in period 1 can be derived:

$$\max_{h_1^i} \; \pi_1^i(h_1^1, h_1^2, \cdots, h_1^n)$$

$$= \max_{h_1^i} \; h_1^i\left(P - \alpha\frac{H_1}{S_1}\right) + \beta\left[V_2^{i*}(S_2)\right]; \qquad i = 1, 2, \cdots, n, \tag{7}$$

where β is the discount factor ($0 < \beta < 1$). Substituting the one-period optimal value function in (6) and the stock growth equation into equation (7), the optimization problem for the each harvester can be rewritten as

$$\max_{h_1^i} \quad h_1^i\left(P - \alpha\frac{H_1}{S_1}\right) + \frac{1}{(n+1)^2}\frac{\beta P^2}{\alpha}\left[(1+r)S_1 - H_1\right]; \qquad i = 1, 2, \cdots, n. \tag{8}$$

where the size of fish stock in period 1, S_1, is given exogenously. The best response function for each of the n harvesters is found and summed over the n first-order conditions to find the profit maximizing harvest level for the harvesters in period 1. The equilibrium harvest level for the collective harvesters in period 1 is

$$H_1^* = \frac{n}{n+1}\left[1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1, \tag{9}$$

Dividing the equation by n gives the optimal harvest level for each harvester in period 1:

$$h_1^{i*} = \frac{1}{n+1}\left[1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1; \qquad i = 1, 2, \cdots, n. \tag{10}$$

This is the subgame perfect equilibrium for the n harvesters in period 1.

Using the objective function in (8), the two-period optimal value function for each harvester is found by substituting in the subgame perfect equilibrium harvest levels of the collective harvesters in (9) and individual harvester in (10):

$$V_1^{i*} = \frac{1}{(n+1)^2}\left[\left(1 - \frac{n^2}{(n+1)^2}\frac{\beta P}{\alpha}\right)\left(1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha}\right) + \beta(1+r)\right]\frac{P^2}{\alpha}S_1;$$

$$i = 1, 2, \cdots, n. \tag{11}$$

Note that the subgame perfect equilibria in (9), (10), and (11) can be solved for an infinite-period horizon (steady state).[3] However, the comparative statics cannot be used for the steady state equilibria because they include a very complex square term. Hence, only a two-period Cournot model is used in this paper.

For the empirical analysis, however, the two-period optimal value cannot be observed; hence, the first-period profit level (π_1^{i*}), which is observable, is used as a proxy of the two-period optimal value (V_1^{i*}). Substituting the equilibrium harvest level for the collective harvesters in (9) and for the individual harvester in (10) into the first term in the objective function in (8), the first-period equilibrium profit level, π_1^{i*}, is

$$\pi_1^{i*} = h_1\left(P - \alpha\frac{H_1}{S_1}\right)$$

$$= \frac{1}{(n+1)^2}\left[1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha}\right]\left[1 + \frac{n}{(n+1)^2}\frac{\beta P}{\alpha}\right]\frac{P^2}{\alpha}S_1. \tag{12}$$

The solutions given in (10) and (12) allow one to prove several testable implications for the WCPO fisheries. Partial derivatives of the equilibrium harvest levels for the individual harvester and the individual equilibrium profit (resource rent) with respect to the number of harvesters *n* are, respectively:

$$\frac{\partial h_1^{j*}}{\partial n} < 0 \qquad \text{and} \qquad \frac{\partial \pi_1^{j*}}{\partial n} < 0.$$

These results lead to the following proposition (see the Appendix A for proofs of the propositions).

Proposition 1: *An increase in the number of harvesters in a common property fishery increases reduces both the equilibrium harvest and profit (resource rent) level for the individual harvester.*

Entry affects fishing cost through both dynamic stock and static crowding externalities. The dynamic stock externality decreases user cost by reducing stock size in the second period, conversely, the static crowding externality increases the harvesting cost in

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[3] The steady state solutions for the collective and individual equilibrium harvest, and individual optimal value are, respectively (the subscript ss denotes the steady-state level):

$$H_{ss}^{*} = \frac{n}{n+1}\Delta\frac{P}{\alpha}S_{ss} \;; \quad h_{ss}^{i*} = \frac{1}{n+1}\Delta\frac{P}{\alpha}S_{ss} \;; \quad \text{and} \quad V_{ss}^{i*} = \tilde{d}_{ss}S_{ss} \qquad i = 1, 2, \cdots, n,$$

where $\Delta = 1 - \dfrac{\beta\tilde{d}_{ss}}{P}$ and $\tilde{d}_{ss} = \dfrac{(n^2+1)P\beta + (n+1)^2\alpha[1-\beta(1+r)] - \sqrt{\omega}}{2n^2\beta^2}$ and

$$\omega = (n^2-1)^2P^2\beta^2 + 2(n+1)^2(n^2+1)\alpha P\beta[1-\beta(1+r)] + (n+1)^4\alpha^2[1-\beta(1+r)]^2.$$

each period. In total, the net harvesting costs increase, which reduces the harvest levels of the individual harvester. Entry and the corresponding externalities, therefore, reduce the resource rent for all harvesters by reducing profits in both periods.

Comparative statics show other implications for the fishery in the WCPO. The partial derivatives of the equilibrium harvest level for the individual harvester, and the individual equilibrium profit with respect to parameter P, α, β and S are, respectively (see the Appendix B for derivations):

$$\frac{\partial h_1^{i*}}{\partial P} > 0, \qquad \frac{\partial \pi_1^{i*}}{\partial P} > 0,$$
$$\frac{\partial h_1^{i*}}{\partial \alpha} < 0, \qquad \frac{\partial \pi_1^{i*}}{\partial \alpha} < 0,$$
$$\frac{\partial h_1^{i*}}{\partial \beta} < 0, \qquad \frac{\partial \pi_1^{i*}}{\partial \beta} > 0,$$
$$\frac{\partial h_1^{i*}}{\partial S} > 0, \qquad \frac{\partial \pi_1^{i*}}{\partial S} > 0.$$

The discount factor can be written as $\beta = 1/(1+\delta)$, where δ is the periodic discount rate. Hence, the partial derivatives of the three equilibrium levels with respect to the discount rate is

$$\frac{\partial h_1^{i*}}{\partial \delta} > 0, \qquad \frac{\partial \pi_1^{i*}}{\partial \delta} < 0.$$

3. 2 The extended model for variable number of harvesters

Up to now, the number of harvesters (n) is assumed to be fixed in both period 1 and 2. However, the expectation of the next period n might affect the three equilibrium levels in the current period. So the extension is that the number of harvesters (n) is allowed to change between the two periods in the basic model (the other parameters remain fixed between the two periods). Let n_1 and n_2 denote the number of harvesters in period 1 and 2, respectively. If the number of harvesters (n) is allowed to change between the two periods; the three equilibrium levels in equations (9), (10), and (12) can be rewritten, respectively as:

$$H_1^* = \frac{n_1}{n_1+1}\left[1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1; \tag{13}$$

$$h_1^{i*} = \frac{1}{n_1+1}\left[1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1; \text{ and} \tag{14}$$

$$\pi_1^{i*} = \frac{1}{(n_1+1)^2}\left[(n_1+1)\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right)-n_1\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right)^2\right]\frac{P^2}{\alpha}S_1. \tag{15}$$

Using the alternative equilibrium solutions in (14) and (15), the partial derivatives of the equilibrium harvest levels for the individual harvester, and the equilibrium profit level for the individual harvester with respect to n_1 are, respectively:

$$\frac{\partial h_1^{i*}}{\partial n_1} < 0, \qquad \frac{\partial \pi_1^{i*}}{\partial n_1} < 0.$$

Also, the partial derivatives of the two equilibrium levels with respect to n_2 are, respectively:

$$\frac{\partial h_1^{i*}}{\partial n_2} > 0, \qquad \frac{\partial \pi_1^{i*}}{\partial n_2} > 0.$$

These results can be summarized in the following proposition.

Proposition 2: *If the number of harvesters changes between the current and next period, an increase in the number of harvesters in the current period reduces both the equilibrium harvest and profit (resource rent) level for the individual harvester. On the other hand, an increase in the number of harvesters in the next period, which is the future expectation of the number of harvesters, increases all three equilibrium levels.*

While the effects of the current entry on the equilibrium levels are the same as the ones by the original case in proposition 1, the effects of the expected future entry are different from the original results. The individual harvesters increase both the equilibrium harvest and profit level if they expect the future entry will increase, given fixed current harvesters. There is no dynamic stock externality since the current number of harvesters does not change, but, the static crowding externality increases the harvesting cost only in the second period, which decreases user cost. As a result, the reduced user cost, which implies the reservation of the stock is less valuable, causes a higher equilibrium harvest level. Further, the increase in the harvest level results in a greater first-period profit without static crowding externality in the first period.

4. The Empirical Model

The econometric equations to be estimated are based on two equilibrium equations in the previous section: the individual equilibrium harvest (h) in equation (10) and the first-period equilibrium profit for each harvester (π) in equation (12). These two equilibrium levels (dependent variables) are identified as a function of five independent variables: the number of harvesters (fishing vessels) (n); the price of the skipjack harvested (P); the cost parameter (α); the discount rate (δ); and the fish stock (S).

For empirical analysis, the cost parameter (α) is provided by average (total) cost (i.e., unit cost of harvest), which is the total cost divided by the total harvest (hereafter, the cost parameter (α) is called average cost). The average total cost includes average fixed cost, for which the depreciation of vessel, building, and equipment is used. Note that catch per unit effort (CPUE) is used as a proxy of skipjack and tuna stock level (S) in the WCPO, because there are no reliable data for the skipjack and tuna stock in the WCPO. This is based on the assumption (i.e., the catch-per-unit-effort hypothesis or the Schaefer hypothesis) that CPUE is proportional to the current stock size (Clark, 1990).[4]

There might be, however, two problems with these explanatory variables. First, it is merely an hypothesis that the CPUE is a linear function of the fish stock. If it is not a linear but rather a nonlinear function, then the CPUE hypothesis results in a specification error due to omitting a relevant explanatory variables (e.g., the omission of the square term of the fish stock). Hence, the OLS estimator of the coefficients will be biased and inconsistent, and the OLS estimator of the variance of the coefficients will contain an upward bias. Second, inclusion of both the average cost and the CPUE causes a multicollinearity problem because the CPUE is likely to be highly correlated with the unit variable cost. One of the remedies for this problem is to drop either one of explanatory variables from the model.

In general form, the above two equilibrium levels at time t can be written as a function of n, P, α, δ, and S:

$$h_t = h(n_t, P_t, \alpha_t, \delta_t, S_t) \text{ and} \tag{16a}$$

$$\pi_t = \pi(n_t, P_t, \alpha_t, \delta_t, S_t)\,. \tag{16b}$$

If proposition 1 in Section 3 is correct, then:

i) $h_n(\cdot) < 0$ and

ii) $\pi_n(\cdot) < 0$,

where subscripts indicate partial derivatives with respect to n. On the other hand, if proposition 2 in Section 3 is true, then:

iii) $h_{n_1}(\cdot) < 0$, $h_{n_2}(\cdot) > 0$ and

iv) $\pi_{n_1}(\cdot) < 0$, $\pi_{n_2}(\cdot) > 0$;

where subscripts indicate partial derivatives with respect to n_1 and n_2 (i.e., n is divided into two terms: n_1 and n_2).

Figure 2 shows the relationship between two equilibrium levels (h_t and π_t) and the number of harvesters (n_t) for a given level of other right-hand-side explanatory variables: P =

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[4] The Schaefer hypothesis is expressed as $H = qES$, where H, q, E, and S denotes the catch rate, the catchability coefficient, fishing effort, and the fish stock, respectively (Schaefer, 1954). Hence, the CPUE is shown as:

$$\frac{H}{E} = qS\,,$$

which is a linear function of the fish stock level.

1, α = 1, β = 0.9, r = 0.5, and S = 1. These relationships can be approximated by using an exponential function [5], so that the following exponential function is used as an approximation for the general model:

$$h_t = \lambda_h \cdot n_t^{\gamma_1} \cdot u_{h,t} \quad \text{and} \tag{17a}$$

$$\pi_t = \lambda_\pi \cdot n_t^{\theta_1} \cdot u_{\pi,t}, \tag{17b}$$

where *u's* are disturbance terms at time t, which is added because of random errors in optimization, and $\lambda_h = e^{\gamma_0} P_t^{\gamma_2} \alpha_t^{\gamma_3} \delta_t^{\gamma_4} S_t^{\gamma_5}$ and $\lambda_\pi = e^{\theta_0} P_t^{\theta_2} \alpha_t^{\theta_3} \delta_t^{\theta_4} S_t^{\theta_5}$. It is assumed that errors (u's) enter multiplicatively because some common unmeasurable or omitted variables will create proportionately large errors in large harvest or profit years. Taking natural logs of both sides of equations (17a) and (17b) gives a log-linear specification:

$$\ln h_t = \gamma_0 + \gamma_1 \ln n_t + \gamma_2 \ln P_t + \gamma_3 \ln \alpha_t + \gamma_4 \ln \delta_t + \gamma_5 \ln S_t + \varepsilon_{h,t} \quad \text{and} \tag{18a}$$

$$\ln \pi_t = \theta_0 + \theta_1 \ln n_t + \theta_2 \ln P_t + \theta_3 \ln \alpha_t + \theta_4 \ln \delta_t + \theta_5 \ln S_t + \varepsilon_{\pi,t}, \tag{18b}$$

where $\varepsilon = \ln u$, and β, γ, and θ are coefficients to be estimated. The log-linear equation in (18b), however, cannot be used for estimation in this paper because the data on individual harvester's profit include some negative values. Therefore, instead of using log-linear form, a semilog specification is used for the first-period profit equation in (18b):

$$\pi_t = \theta_0 + \theta_1 \ln n_t + \theta_2 \ln P_t + \theta_3 \ln \alpha_t + \theta_4 \ln \delta_t + \theta_5 \ln S_t + \varepsilon_{\pi,t}, \tag{18c}$$

where the original exponential equation for the semilog specification is: $e^{\pi_t} = \lambda_\pi \cdot n_t^{\theta_1} \cdot u_{\pi,t}$.

For the test of proposition 2, another term for the expected number of future harvesters, n^e, is added in the model: $\gamma_6 \ln n_t^e$ (18a) and $\theta_6 \ln n_t^e$ (18c). For this term, it is assumed that the harvesters' expectation in the next period is a trend of the number of harvesters between the previous and current period. In this paper, the number of harvesters in the next period is used for the expected number of future harvesters (n^e).

The disturbances at a given time in two equations are likely to reflect some common unmeasurable or omitted factors; hence, they could be correlated (i.e., contemporaneous correlation). When this is the case, it may be more efficient to estimate all equations (18a and 18c) jointly rather than to estimate by using equation-by-equation ordinary least squares

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[5] This nonlinear shape is created by the cost function in equation (1).

(OLS). In these two equations, however, the right-hand-side explanatory variables in these two equations are identical so that the parameter estimates by SUR estimation are identical with that by equation-by equation OLS estimation (there is no efficiency gain). In this paper, therefore, equation-by-equation OLS is used for the estimation.

In this econometrics model, there might be a simultaneity problem. The expected number of future harvesters (n^e) and the first-period profit (π) might be endogenous. The number of future harvesters may depend on the current profit level. If a simultaneity problem exists, the OLS estimator is biased and inconsistent, so that two stage least squares (2SLS) or three stage least squares (3SLS) estimation should be used, if any, with instrumental variables. When samples are extremely small, however, the distributions for 2SLS and 3SLS estimators are not known to be normal and the mean of the 2SLS estimator may not exist. In addition, in small samples, the OLS estimator (despite their inconsistency) has a lower variance than the 2SLS estimator (Judge, *et al.*, 1988, pp. 655). Therefore, the 2SLS and 3SLS estimation may not be appropriate methods to use with these data.

The theoretical analysis in the previous section tells us *a priori* the signs of the parameters: $\gamma_1 < 0$, $\gamma_2 > 0$, $\gamma_3 < 0$, $\gamma_4 > 0$, $\gamma_5 > 0$, and $\gamma_6 > 0$ for the individual harvest equation (h) and $\theta_1 < 0$, $\theta_2 > 0$, $\theta_3 < 0$, $\theta_4 < 0$, $\theta_5 > 0$, and $\theta_6 > 0$ for the first-period profit equation (π). For the purpose of this paper, the main parameters of interest are γ_1, γ_6, θ_1, and θ_6.

5. Data

The empirical analysis uses data from the Japanese pole and line fishery, which harvested skipjack stock in the WCPO from 1972 to 1998. These data are used as a proxy of purse seine fishery for the skipjack and tuna in the WCPO because the data for the Japanese purse seine fishery are not available. The Japanese government publishes annual economic data for many kinds of fisheries in the *Investigation Report of Fishery Economics* by the Ministry of Agriculture, Forestry and Fishery (Japan).[6] These data are not for individual vessel levels but an average of randomly selected vessels (i.e., group mean data [7]) The observation number is 27 (time series). In each year, the numbers of randomly selected samples (harvesters) are different. The data are collected by questionnaires and direct interviews from randomly selected harvesters. The data include average vessel weight, number of working days and workers, total revenue from the fishery, variable costs (including

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[6] The English titles for the Japanese publications in this section are translated from Japanese by the author.

[7] There are two effects when the group mean date is used. First, the parameter estimates are less efficient because of the loss of information. Second, the fit of the regression sometime improves greatly. See Green (1990), pp.289-293.

labor, fuel, material, repair cost, fees, and other cost), fixed capital cost, capital depreciation and wages (for one person a day).

For the data on dependent variables, the individual harvest of skipjack (h), which is not available, is calculated by dividing the total revenue by the price of the skipjack. The data for the total revenue come from the *Investigation Report of Fishery Economics* by the Ministry of Agriculture, Forestry and Fishery (Japan). The sizes of the pole and line vessels are all between 200 to 500 tons with an average of 402 tons between 1972 and 1998. As a proxy of two-period value (V), the individual harvester's profit (π) is calculated by subtracting total cost (variable cost plus capital depreciation) from total revenue, which comes from the *Investigation Report of Fishery Economics* by the Ministry of Agriculture, Forestry and Fishery (Japan).

For the data on explanatory variables, the number of harvesters (n) in the WCPO is obtained from the *Tuna Fishery Yearbook 1999* (see Table 1). The expected number of future harvesters (n^e) is using the number of harvesters (n) in the next year. In addition, the data for the price of the harvested skipjack (P) is obtained from the *Annual Statistical Report of Fishery Product Market* by the Ministry of Agriculture, Forestry and Fishery (Japan). The discount rate (δ) used is the 10 year government bond yield to subscribers, which is obtained from the *Economic Statistics Annual* by the Research and Statistics Department, Bank of Japan. The other explanatory variables, cost parameter (α) and fish stock (S), are substituted by using (total) average cost and catch per unit effort, respectively. The former is derived by dividing total cost (variable cost plus capital depreciation) by the individual harvest level (yen / tons) and the latter is calculated by dividing the total skipjack catches by vessel-days, which is measured by the number of the vessels multiplied by the number of working days (tons / vessels-days).

6. Empirical Results

Table 2 presents the estimation results of the regression equations based on the individual equilibrium harvest (h) in (18a). The equilibrium equation is estimated by equation-by-equation ordinary least squares (OLS). There are two specifications: one is for proposition 1 and the other is for proposition 2, which is added an expected harvest term. The fish stock term (S) is dropped from the equations to be estimated because CPUE has extremely small correlation with other variables, which indicates the assumption (CPUE is proportional to the current stock size) is not the case in this study. Estimates of the standard errors are shown in parentheses below the estimates of the coefficients. For t-test of each parameter estimate, a one-tailed test is used because the theoretical model in Section 3 provides all signs of the parameter estimates. One, Two, and three stars indicate that parameter estimates are statistically significant at the 10%, 5%, and 1% confidence level, respectively.

In the first specification for proposition 1, the estimated coefficients for the number of harvesters (n) and the discount rate (δ) have the unexpected signs. The other variables, the price of skipjack (P) and the average cost (α), have the expected signs, that are statistically significant at the 1% confidence level. The estimated price elasticity of supply is 0.7465 (i.e., inelastic), which is statistically significant at the 1% confidence level. The adjusted R^2 is high of 0.9564 and the Durbin-Watson (DW) statistics is 1.7411.

In the second specification for proposition 2, the estimated coefficients for the number of harvesters (n), the expected number of harvesters (n^e), and the discount rate (δ) have the unexpected signs. The other variables, the price of skipjack (P) and the average cost (α), have the expected signs, that are statistically significant at the 5% and 1% confidence level, respectively. The estimated price elasticity of supply is 0.6417 (i.e., inelastic), which is statistically significant at the 1% confidence level. The adjusted R^2 is high of 0.9556 and the Durbin-Watson (DW) statistics is 1.7138.

Table 3 shows the estimation results on the first-period profit (π) in (18c) by equation-by-equation OLS. The estimated coefficients of the all variables perfectly have the expected signs in both specifications. In the first specification for proposition 1, the estimated coefficients for the number of harvesters (n) are statistically significant at the 5% confidence level. The other variables, the price of skipjack (P) and the average cost (α), are both statistically significant at the 1% confidence level. In the second specification for proposition 2, on the other hand, the estimated coefficients for the number of harvesters (n) and the expected number of harvesters (n^e) are statistically significant at the 5% and 10% confidence level, respectively. The price of skipjack (P) and the average cost (α) are also statistically significant at the 1% confidence level. The discount rate (δ) have the expected signs in both equations, but they are not statistically significant. The adjusted R^2s in both specifications are 0.9032 and 0.9014, respectively and the Durbin-Watson (DW) statistics are 1.9094 and 1.9158, respectively.

To summarize, the econometric model based on two equilibrium equations is estimated by equation-by-equation OLS estimation. The estimation is also used for the alternative specification for proposition 1 and proposition 2 that is adding the expected harvester's term (n^e). The parameter estimates on current number of harvesters (n) and expected harvesters (n) have unexpected signs in the individual equation. This is because the data of individual harvest of skipjack is not available. Note that they are generated by dividing the total revenue by the price of the skipjack. Hence, the result may not be reliable very much. In the first-period profit equation, on the other hand, the parameter estimates on current number of harvesters (n) and expected number of harvesters (n^e) have expected signs and are statistically significant. All other parameter estimates have also expected signs and statistically significant ,except that the parameter estimates on discount rate is not significant. These results of the perfect expected signs for the equilibrium profit equation support the predictions in propositions 1 and 2, although the results for the individual harvest equation do not support the propositions.

7. Conclusion

This paper utilizes the dynamic Cournot oligopoly model of Negri (1990) and analyzes the effect of the current and future number of harvesters on individual equilibrium harvest level and equilibrium resource rents. The model allows us to test two hypotheses. One is that an increase in the number of harvesters in a common property resource fishery reduces both the equilibrium harvest level and the resource rent of each harvester. The other is that an increase in the future expectation of the number of harvesters increases both two equilibrium levels.

The hypotheses are tested by using data from the Japanese skipjack pole and line fishery, which harvested the skipjack stock from the Western-central Pacific Ocean between 1972 and 1998. The empirical results show that the parameter estimates for the current and future number of harvesters are of the predicted sign in equilibrium resource rent equation, and they are all statistically significant. That is, the empirical results provide some evidence that the Japanese skipjack harvesters operated the common property resource fishery by responding to the current and future number of harvesters in the WCPO.

While the above empirical results are consistent with the dynamic Cournot game theory, some caution should be used in interpreting the empirical results. The estimations in this study are based on many proxy data, so the results may not be very reliable. Also, the data used in this study are average sample data from the Japanese skipjack pole and line fishery only, which is not the purse seine fishery in the WCPO. Moreover, direct measurement of skipjack stock in the WCPO is not available. To obtain more reliable results, it is essential to collect more data. This analysis is left for future research.

Appendix

***Proof of Proposition 1*:**

For simplicity, we first let:

$$\Theta = 1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha},$$

so that individual equilibrium harvest level and two-period optimal value function are, respectively :

$$h_1^{i*} = \frac{1}{n+1}\Theta\frac{P}{\alpha}S_1, \text{ and} \tag{A1}$$

$$\pi_1^{i*} = \frac{1}{n+1}\left(\Theta - \frac{n}{n+1}\Theta^2\right)\frac{P^2}{\alpha}S_1 . \tag{A2}$$

Consider first the partial derivative of Θ with respect to a parameter *n* (the number of harvesters). We can show its sing as follows:

$$\frac{\partial\Theta}{\partial n} = \frac{2}{(n+1)^3}\frac{\beta P}{\alpha} > 0 . \tag{A3}$$

Then, by using (A3), we can show the sign of the partial derivative of the individual equilibrium harvest with respect to the parameter *n* is:

$$\begin{aligned}\frac{\partial h_1^{i*}}{\partial n} &= \left[-\frac{1}{(n+1)^2}\Theta + \frac{1}{n+1}\frac{\partial\Theta}{\partial n}\right]\frac{P}{\alpha}S_1 \\ &= \left[-\frac{1}{(n+1)^2} + \frac{1}{(n+1)^4}\frac{\beta P}{\alpha} + \frac{2}{(n+1)^4}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1 \\ &= -\frac{1}{(n+1)^2}\left[1 - \frac{3}{(n+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1 < 0 ,\end{aligned} \tag{A4}$$

since the terms in the brackets are positive ($n \geq 1$).

Taking the partial derivative of (A2) with respect to *n* gives:

$$\begin{aligned}\frac{\partial\pi_1^{i*}}{\partial n} &= -\frac{1}{(n+1)^2}\Theta + \frac{1}{n+1}\frac{\partial\Theta}{\partial n} + \frac{n-1}{(n+1)^3}\Theta^2 - \frac{2n}{(n+1)^2}\Theta\frac{\partial\Theta}{\partial n} \\ &= -\left(1 - \frac{n-1}{n+1}\Theta\right)\Theta - \left[\frac{2n}{n+1}\left(1 - \frac{1}{(n+1)^2}\frac{\beta P}{\alpha}\right) - 1\right]\frac{\partial\Theta}{\partial n} \\ &= -\left(1 - \frac{n-1}{n+1}\Theta\right)\Theta - \frac{1}{(n+1)^2}\left[n - 1 + \frac{1}{(n+1)}\frac{\beta P}{\alpha}\right]\frac{\partial\Theta}{\partial n} .\end{aligned} \tag{A5}$$

By (A3) and (A5), we can finally show:

$$\frac{\partial\pi_1^{i*}}{\partial n} < 0 . \tag{A6}$$

Hence, by (A4) and (A6), the proposition 1 holds.

***Proof of Proposition 2*:**

Taking the partial derivative of the individual equilibrium harvest in equation (10) with respect to n_1 and n_2 gives, respectively as

$$\frac{\partial h_1^{i*}}{\partial n_1} = -\frac{1}{(n_1+1)^2}\left[1 - \frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1 < 0 \quad \text{and} \tag{A7}$$

$$\frac{\partial h_1^{i*}}{\partial n_2} = -\frac{1}{(n_1+1)}\left[\frac{2}{(n_2+1)^3}\frac{\beta P}{\alpha}\right]\frac{P}{\alpha}S_1 > 0 . \tag{A8}$$

Finally, the partial derivative of the individual first-period profit in equation (12) with respect to n_1 and n_2 can be derived, respectively as

$$\frac{\partial \pi_1^{i*}}{\partial n_1} = \left[-\frac{1}{(n_1+1)^2}\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right) - \frac{n_1-1}{(n_1+1)^3}\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right)^2 \right]\frac{P^2}{\alpha}S_1 < 0 \quad \text{and} \qquad (A9)$$

$$\frac{\partial \pi_1^{i*}}{\partial n_2} = \left[\frac{1}{(n_1+1)}\left(\frac{2}{(n_2+1)^3}\frac{\beta P}{\alpha}\right) - \frac{1}{(n_1+1)^2}\left(\frac{2}{(n_2+1)^3}\frac{\beta P}{\alpha}\right)\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right)^2 \right]\frac{P^2}{\alpha}S_1$$

$$= \frac{1}{(n_1+1)}\left(\frac{2}{(n_2+1)^3}\frac{\beta P}{\alpha}\right)\left[1-\frac{2n_1}{(n_1+1)^2}\left(1-\frac{1}{(n_2+1)^2}\frac{\beta P}{\alpha}\right)\right]\frac{P^2}{\alpha}S_1 > 0 \text{ .(A10)}$$

Therefore, by (A7) through (A10), the proposition 2 holds.

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Table 1. Total number of purse seine vessels in the Western-central Pacific Ocean by country, 1969-1999.

Year	Japan	United State	Korea	Taiwan	Philippine s	New Zealand	Solo- mon Islands	Russia	Federated State of Micro-nesi a	Papua New Guinea	Vanuatu	Australia	Indonesia	Spain	Kiribati	Mexico	Total
1969	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
1970	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
1971	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
1972	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
1973	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
1974	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
1975	12	-	-	-	-	...	-	-	-	-	-	-	-	-	-	-	12
1976	15	3	-	-	-	...	-	-	-	-	-	-	-	-	-	-	18
1977	14	1	-	-	-	...	-	-	-	-	-	-	-	-	-	-	15
1978	14	2	-	-	-	...	-	-	-	-	-	-	-	-	-	-	16
1979	17	8	-	-	-	...	-	-	-	-	-	-	-	-	-	-	25
1980	16	14	2	-	-	...	1	-	-	-	-	-	-	-	-	-	33
1981	23	14	3	-	-	...	1	-	-	-	-	-	-	-	-	-	41
1982	33	24	10	-	1	...	1	-	-	-	-	-	-	-	-	-	69
1983	36	62	11	3	-	7	1	-	-	-	-	-	-	-	-	-	120
1984	33	61	12	6	3	5	1	-	-	-	-	-	...	-	-	1	122
1985	35	40	11	7	5	5	1	5	-	-	-	-	...	-	-	5	114
1986	38	36	13	10	5	4	1	8	-	-	-	-	3	-	-	-	118
1987	34	35	20	13	5	3	2	5	-	-	-	-	3	-	-	-	120
1988	39	31	23	19	9	4	4	5	-	-	-	3	3	-	-	-	140
1989	37	35	30	25	13	5	4	5	-	-	-	1	3	-	-	-	158
1990	35	43	39	32	13	5	4	5	-	-	-	8	...	-	-	-	184
1991	35	43	36	39	15	5	3	4	6	-	-	6	-	-	-	-	192
1992	38	44	36	45	12	7	3	3	7	-	-	2	-	-	-	-	197
1993	36	42	34	43	12	5	3	8	7	-	-	1	-	-	-	-	191
1994	33	49	32	43	11	7	3	4	8	2	1	-	-	-	1	-	194
1995	31	44	30	42	13	5	3	...	6	3	2	-	-	-	1	-	180
1996	32	40	28	42	12	6	3	...	4	4	2	-	-	-	1	-	174
1997	35	35	27	42	12	7	4	...	4	10	5	-	-	-	1	-	182
1998	35	39	26	42	12	6	4	...	3	13	5	-	-	-	1	-	186
1999	35	36	26	42	(12)	6	4	...	4	13	9	-	-	8	1	-	184

Note: Symbols '...' = missing data; estimates in parentheses have been carried over from previous years.

Source: Timothy A. Lawson (1999) *Tuna Fishery Yearbook 1999*

Table 2

Parameter estimates on the individual harvest (h) equation.
(log-linear form)

Variables	Specification for proposition 1	Specification for proposition 2
Constant	12.870***	13.383***
	(0.8817)	(1.0910)
Number of harvesters	0.0351†	0.0465†
(n)	(0.1254)	(0.1297)
Expected harvesters	-	-0.1108†
(n^e)	-	(0.1378)
Price of skipjack	0.7465***	0.6417**
(P)	(0.2624)	(0.2966)
Average cost	-1.7215***	-1.6075***
(α)	(0.2809)	(0.3199)
Discount rate	-0.1002†	-0.0853†
(δ)	(0.1016)	(0.1071)
Fish Stock	-	-
(S)	-	-
Adjusted R^2	0.9564	0.9556
DW	1.7411	1.7138

Standard errors are in parentheses.

** Statistically significant at 5 % significance level (one-tailed test).

*** Statistically significant at 1 % significance level (one-tailed test).

† Unexpected sign.

Table 3

Parameter estimates on the first-period profit (π) equation.
(semilog form)

Variables	Specification for proposition 1	Specification for proposition 2
Constant	-23.409	-10.213
	(25.730)	(28.509)
Number of harvesters	-2.4806**	-15.335**
(n)	(1.3031)	(8.5752)
Expected harvesters	-	13.698*
(n^e)	-	(9.4184)
Price of skipjack	292.58***	311.95***
(P)	(19.931)	(23.361)
Average cost	-287.36***	-309.85***
(α)	(19.008)	(23.720)
Discount rate	1.5443	1.7150
(δ)	(3.2679)	(3.4946)
Fish Stock	-	-
(S)	-	-
Adjusted R^2	0.9032	0.9014
DW	1.9094	1.9158

Standard errors are in parentheses.

* Statistically significant at 10 % significance level (one-tailed test).

** Statistically significant at 5 % significance level (one-tailed test).

*** Statistically significant at 1 % significance level (one-tailed test).

† Unexpected sign.

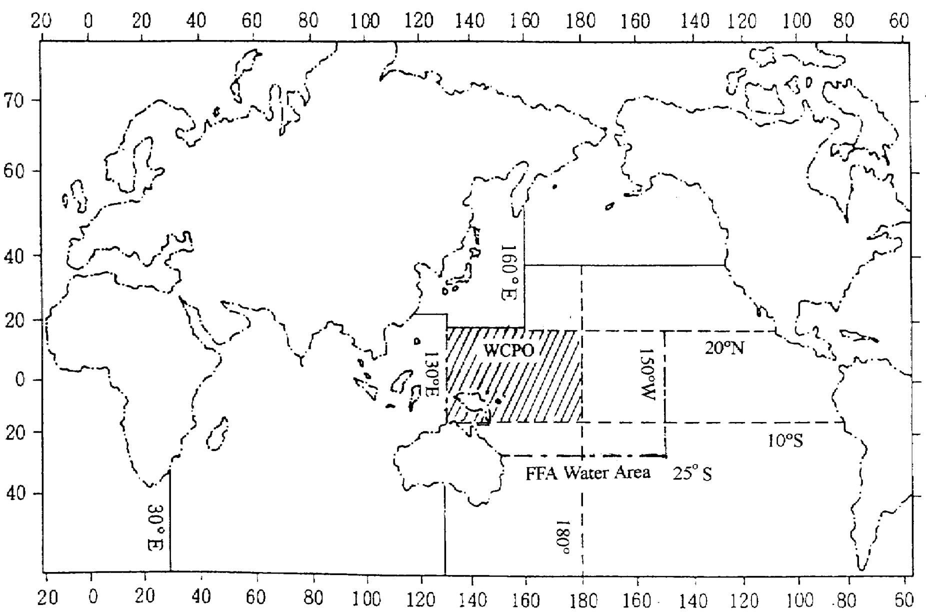

Figure 1. Japanese division of Pacific Ocean and FFA water area.

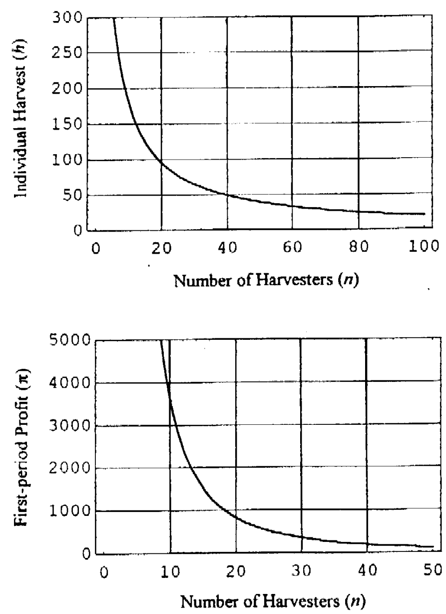

Figure 2. Relationship between number of harvesters and two equilibrium levels.