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Optimal Number of Fishing Vessels for Taiwan's Offshore Fisheries: A Comparison of Different Fleet Size Reduction Policies

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Abstract *This study compares the harvest capacity of Taiwan's offshore fishing fleet to sustainable yields of offshore fisheries and evaluates different legislative strategies designed to reduce the fishing fleet. Aggregate offshore fisheries' stock changes and harvest functions are specified and estimated. Results show that the stock has been declining since 1973. Based on dynamic simulations, this study shows that neither the program to restrict the building of new vessels nor a combination of this program with the vessel retirement and buy back program is sufficient to avoid the downward trend in harvests and the deteriorating state of stocks. While reducing fishing effort to the maximum sustainable yield (MSY) level might suffice as an initial vessel reduction measure, attaining MSY within 5 to 10 years seems preferable over a one-year approach. The long-run economic situation would be further improved by an additional reduction of fishing effort to the optimal yield (OY) level.*

Key words Aggregate stock change and harvest function, maximum sustainable yield (MSY), offshore fishery, optimal yield (OY), Taiwan.

Introduction

In order to maintain the sustainability of Taiwan's offshore fisheries stocks and to avoid overfishing, Taiwan has implemented a fisheries management policy which regulates harvests by suspending fishing licenses, restricts construction of fishing vessels, and buys back used vessels in order to reduce the offshore fleet size.

The offshore fisheries harvests in Taiwan reached a peak in 1978, after which they began to decrease. If this decrease is the result of overfishing, as is very probable, then this downward trend is likely to continue. On the other hand, the number of fishing vessels, total vessel tonnage, and total horsepower of vessels increased at least until 1989. In 1993, adjusted offshore fisheries harvests, vessel numbers, total vessel tonnage, and total horsepower were 5.5, 3.2, 7.8, and 35.2 times greater, respectively, than in 1953. Since the average harvest per vessel ton has followed a decreasing trend after 1963, there is a tendency towards overcapitalization.

In response to this situation, four amendments that regulate the number of off-

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shore fishing vessels in Taiwan were enacted in 1967, 1980, 1989, and 1991.[1] The most recent measure, which is still in effect, restricts the construction of all fishing vessels, except for fish transport vessels over 2,000 tons. Furthermore, a major revision of the Fisheries Law[2] in 1991 gave the government the explicit right to adjust the fishing effort according to resource abundance. The government has the right to limit the number of vessels, total vessel tonnage, fishing area, fishing period, and all other aspects of fishing vessel management policy for the following reasons: (1) fisheries conservation; (2) fisheries structural adjustment; and (3) restrictions resulting from international agreements or cooperation.

In 1991, in addition to the overall restriction on the construction of fishing vessels, the government adopted a voluntary vessel retirement and buy back program in order to reduce Taiwan's fleet size (Taiwan Fisheries Bureau 1992–94). The questions that remain, however, are how to evaluate the impact of the current vessel reduction management programs and how to determine the optimal reduction scheme that reaches maximum sustainable yield (MSY) or optimal yield (OY) most efficiently.

Since the fishing industry pays nothing to access the fish, and because fisheries resources are somewhat scarce, fishing effort tends to be excessive (Hannesson 1993). A successful vessel reduction program should be based on maintaining the sustainability of the fisheries stocks while adjusting harvests. Fisheries regulations covering vessel and fleet operations are necessary and should be a combination of government policies and programs which limit open access to the resource and manage access according to optimal timing patterns (Anderson 1986).

Many countries ostensibly set out to reduce the capacity of their fishing fleets with the intent of increasing long-term industry profits. For example, as part of an EU multi-annual guidance program, MAGP III was announced by the European Parliament in 1993, which is a four-year decommissioning scheme introduced in England, Scotland, Northern Ireland, and Wales (OECD 1997). The decommissioning was viewed as a "necessary evil" because reducing the aging fleet profile was the first step in the long-term plan for the industry (*Fishing News* 1995).

The purpose of this study is to estimate MSY, maximum economic yield (MEY), and OY for Taiwan's offshore fisheries and to evaluate the impact of current vessel reduction programs. First, aggregate fisheries stock dynamics and a harvest function are established. The Schaefer model, which features a primitive Cobb-Douglas production function and a logistic growth equation, has often been used by economists concerned with harvest functions for fisheries (Anderson 1986; Clark 1990; Hannesson 1983; Opsomer and Conrad 1994; Schaefer 1954; Comitini and Huang 1967; Hannesson 1983; Tomkins and Butlin 1975; Tsoa, Schrank and Roy 1984). A variant of this model is used to evaluate the effect of alternative vessel reduction programs. The intention is to provide the offshore fishing industry with alternative perspectives for its future and to help government policymakers evaluate the impact of alternative vessel reduction policies.

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[1] For example, in 1967, in order to prevent any further increase in the existing number of pair trawlers under 120 tons and otter trawlers under 200 tons, the Council of Agriculture applied measures to restrict the construction of both types of trawlers (Department of Agriculture and Forestry 1993). In 1989, the Council of Agriculture further amended the already existing fishing boat building restrictions to accept only: tuna purse seiners over 1,000 tons, group purse seiners for mackerel, fish transporting vessels of 2,000 tons and over, and factory vessels of 2,000 tons and over (Department of Agriculture and Forestry 1993).

[2] In 1990, the Council of Agriculture drafted an "Adjustment Measure on Offshore Fisheries." Under this measure, assistance was rendered to fishermen who would otherwise have utilized the migratory resources of pelagic and sub-pelagic stocks. This relieved the pressure on demersal stocks, thereby achieving the goal of gradually directing fishery development from resource consumption to resource conservation (Department of Agriculture and Forestry 1990).

Data

Yearly aggregate offshore fisheries data obtained from the Taiwan Fisheries Bureau for the period 1978 to 1994 are used to establish aggregate fisheries dynamic movements and harvest functions. Annual offshore fisheries harvest quantities, production values, and aggregate data on fishing vessels were obtained from the *Fisheries Yearbook for Taiwan Area* for the period 1953 to 1993,[3] which is the most recent data available (Taiwan Fisheries Bureau 1978–94). Aggregate data on fishing vessels includes the number of fishing vessels, vessel tonnage, and average horsepower per vessel ton for motor powered fishing units.

Offshore fisheries are defined as powered vessels fishing within the Economic Exclusive Zone (EEZ) around Taiwan, which is under the Taiwan's jurisdiction by the Law of Fishery. Fishing vessels smaller than 100 tons, which are owned by individual families or small-scale fishing companies, primarily operate in Taiwan's offshore fishery. Some of these small-scale, individual vessels switch back and forth between two or more types of fishing gear, according to season and target species. For target species that have a short life cycle, such as the small subpelagics, the proportional representation of the different species is fairly constant. Although Taiwan's offshore fisheries catch a variety of species, the available data represent only aggregate catch quantities. Consequently, the output side is defined over one composite output variable, aggregate catch quantity.

Empirically, since there are overlapping problems with mainland China and Japan regarding the EEZ fishing grounds, it may also pose a problem to use total harvest and fishing effort directly. Therefore, removal of three types of fishing fleets from the harvest and fishing effort (purse seine mackerel,[4] longline tuna, and trawl fishing fleets with vessels that are over 50 tons and freezer equipped) is proposed in order to avoid the overlapping problems. After this modification, the remaining offshore fishing vessels will then operate anywhere from 12 to approximately 100 nautical miles around Taiwan, which is under Taiwan's jurisdiction, solving the problem of overlapping fishing grounds with mainland China and Japan. This is especially true for three types of fishing fleets with vessels smaller than 100 tons, which may target transboundary or large pelagic stocks or may operate beyond the 200 nautical mile zone around Taiwan.

The cost and revenue data for the different tonnage classes of offshore fishing vessels were obtained from the database released by the *Annual Economic Survey of Offshore Fisheries and Aquaculture* (Taiwan Fisheries Bureau 1992). The revenue and cost data are used to approximate the revenue-cost ratios for fishing vessels in the different tonnage classes. A weighted average revenue-cost ratio is calculated according to the distribution of the offshore fishing vessels in the different tonnage classes as follows:

$$\text{ratio} = \frac{R_1}{C_1} \cdot A_1 + \frac{R_2}{C_2} \cdot A_2 + \frac{R_3}{C_3} \cdot A_3 + \frac{R_4}{C_4} \cdot A_4 + \frac{R_5}{C_5} \cdot A_5$$

where ratio = weighted average revenue-cost ratio; R_i = average revenue per vessel ton of the *i*th ton class (NT$/vessel ton); C_i = average cost per vessel ton of the *i*th ton class (NT$/vessel ton); A_i = percentage of total fishing vessel tonnage repre-

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[3] Aggregate data on fishing vessels for the period 1977 to 1984 were obtained from the *Fishing Vessel Yearbook* since they were not included in the *Fisheries Yearbook* for those years.

[4] This fishery started in 1977 and is operated by the eight fishing fleets. Each fleet is comprised of two light vessels, two shipment vessels, and one purse seine vessel.

Table 1
Offshore Fisheries Production, Revenue, and Cost in Taiwan, 1992

Various Tonnage Classes	Average Yield per Vessel Ton (kg/Ves. Tons) (O)	Average Revenue per Vessel Ton (NT$/Ves. Tons) (A)	Average Cost per Vessel Ton (NT$/Ves. Tons) (B)	Average Variable Cost per Vessel Ton (NT$/Ves. Tons) (C)	Revenue-Cost Ratio (D)	Short-Term Revenue-Cost Ratio (E)	Percentage of Total Vessel Ton (F)
Under 5 tons	2,362	188,442	136,136	81,242	1.38	2.31	5.16%
5–10 tons	2,339	146,777	121,037	81,081	1.21	1.81	8.42%
10–20 tons	1,972	135,705	121,214	83,813	1.11	1.61	19.67%
20–50 tons	1,523	99,349	88,731	65,943	1.11	1.5	58.16%
50–100 tons	1,226	69,993	68,187	40,498	1.02	1.72	8.59%
Weighted average	1,698	112,569	98,522	69,336	1.14	1.62	–

[a] *Annual Economics Survey of Offshore Fisheries and Aquaculture in Taiwan*, 1992, Taiwan Fisheries Bureau.
[b] $(D_i) = (A_i)/(B_i)$, $(E_i) = (A_i)/(C_i)$
[c] *Fisheries Yearbook in Taiwan Area*, 1992, Taiwan Fisheries Bureau.
[d] Weighted average of percentage of total tonnage, the formula equals to $\sum_{i=1}^{5}(k_i \times f_i)$, where k = (A), (B), (C), (D), (E); i = 1, 2, 3, 4, or 5; 1 represents vessels under 5 tons; 2 represents vessels approximately 5–10 tons; 3 represents vessels approximately 10–20 tons; 4 represents vessels approximately 20–50 tons; and 5 represents vessels approximately 50–100 tons.

sented by vessels the *i*th ton class, where 1, 2, 3, 4, and 5 represent 0–5 tons, 5–10 tons, 10–20 tons, 20–50 tons, and 50–100 tons, respectively.

In 1992, the percentages of total vessel tonnage for the five tonnage classes were 5.16%, 8.42%, 19.67%, 58.16%, and 8.59%, respectively (table 1). The average harvest per vessel ton was 1,698 kg, and the average harvest value[5] per vessel ton was NT$112,569. When factoring out the cost of equipment, depreciation and interest cost of capital, the average cost per vessel ton was NT$98,522, and the short-term variable cost[6] was NT$69,336.

The revenue/cost ratio for each of the five tonnage classes ranges from 1.02 to 1.38, with a weighted average of 1.14 (table 1). This means that the average fishing fleet earns a profit. However, the revenue/cost ratio declines as the vessel tonnage increases, which illustrates the phenomenon of overcapitalization (Sun 1995). While it may be true that smaller vessels are more profitable, it is also conceivable that larger vessels could be more profitable if the fisheries were less exploited.

The short-term revenue/cost ratio, which is defined as the average revenue divided by the average variable cost, ranges from 1.50 to 2.31, with a weighted average of 1.62. Thus, when average fixed costs (*i.e.*, equipment depreciation and cost of interest) are not taken into account, which is not the case in the short-run, the average fishing vessel earns a profit. The government will, therefore, have to provide very attractive vessel reduction incentives before fishermen will relinquish such lucrative, short-term fishing opportunities.

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[5] Averaging harvest value assumes that prices for different species were relatively constant over the sample period in 1992.
[6] According to the original data source, this includes all direct and indirect costs. The annual variable cost per vessel ton includes fuel, bait, ice, salt, water, box/basket, food, fish market administration and fee, transportation and storage charge, repair and replacement of fishing gear, salary, and interest cost of a revolving fund.

Model Specification

This study specifies a generalized harvest function which permits the estimation of an unconstrained Cobb-Douglas production function (Comitini and Huang 1967; Hannesson 1983; Tomkins and Butlin 1975; Tsoa, Schrank and Roy 1984):

$$Y_t = H(X_t, E_t) = A_t^q E_t^\alpha X_t^\beta \tag{1}$$

where Y_t is the offshore fisheries harvest in period t; $H(X_t, E_t)$ is the harvest function which depends on X_t and E_t. The variable X_t represents an assessment of offshore fisheries resource stock; E_t represents the fishing effort, which is defined as total vessel tonnage of the offshore fisheries in period t. The variable A_t represents the technological efficiency of the offshore fisheries in period t. Technological efficiency is defined as the improvement of fishing gear, such as replacing engines with more efficient ones to improve fishing yields. Finally, q, α, β are parameters which represent the scale elasticities associated with technological efficiency, fishing effort, and resource stock, respectively.

Suppose that the growth function of the fisheries resource stock in period t is specified as a logistic growth function, $G(X_{t-1})$, which depends on the biomass of the fisheries in the previous period (Schaefer 1954). Hence, the dynamic movement of the fisheries resource stock is specified as follows:

$$X_t - X_{t-1} = G(X_{t-1}) - H(X_{t-1}, E_{t-1}) = rX_{t-1}\left(1 - \frac{X_{t-1}}{K}\right) - Y_{t-1} \tag{2}$$

where r is the intrinsic growth rate, and K is the environmental carrying capacity.

Using equation (1), a function for the resource stock of the fisheries in period $t-1$, (X_{t-1}) can be substituted into equation (2), so that the resource stock of the offshore fisheries in period t can be represented as a function of Y_{t-1}, A_{t-1}, and E_{t-1}:

$$X_t = (1+r)\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^\alpha}\right)^{1/\beta} - \frac{r}{K}\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^\alpha}\right)^{2/\beta} - Y_{t-1}. \tag{3}$$

By substituting equation (3) into equation (1), the current period harvest function for offshore fisheries is specified as a function of the previous period's harvest, Y_{t-1}, technological efficiency, A_{t-1}, and fishing effort, E_{t-1}:

$$Y_t = A_t^q E_t^\alpha \left[(1+r)\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^\alpha}\right)^{1/\beta} - \frac{r}{K}\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^\alpha}\right)^{2/\beta} - Y_{t-1}\right]^\beta. \tag{4}$$

Suppose the error term is multiplicative normal,[7] then the empirical model is specified as follows:

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[7] Uhler assumed that the above model contains two stochastic processes—the harvesting process and the growth process—each process has its own error terms (Uhler 1980). Note that even if these error terms are normally distributed, the composite error terms for the combined model may not be normally distributed.

$$\ln Y_t = q\ln A_t + \alpha \ln E_t + \beta \ln\left[(1+r)\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^{\alpha}}\right)^{1/\beta} - \frac{r}{K}\left(\frac{Y_{t-1}}{A_{t-1}^q E_{t-1}^{\alpha}}\right)^{2/\beta} - Y_{t-1}\right]^{\beta} + \mu_t \qquad (5)$$

where μ_t is the composite error term, and estimates of q, α, β, r, and (r/K) are obtained via maximum likelihood estimation.[8]

Fisheries harvests are measured in tons, and fishing effort is measured in units of 10,000 vessel tons. The log of the average horsepower per vessel is a variable representing technological efficiency. Note that many simplifying assumptions have been made in this analysis. For example, the dynamics of the fish stock could be based on other biological or ecological models. Also, mandated changes in fishing effort and total vessel tonnage were assumed to be implemented fully according to government regulations.

Model Estimation and Results

Since the fisheries harvest function is specified as a nonlinear model, maximum likelihood estimation is used. The estimates are reported in table 2. The signs and magnitudes of all the estimates agree reasonably well with bioeconomic theory. All coefficients are significant, except the coefficient associated with technological efficiency.[9] The root mean square percentage errors (RMSPE)[10] of the above model is 0.57%. The Theil Inequality Coefficients for variance and covariance are 0.003 and 0.997, respectively, indicating that the estimated model can generate simulations that are highly correlated with actual outcomes.

The following parameters can be calculated from the results in table 2. Using the estimated intrinsic growth rate (r = 0.3102) and the estimate of (r/K), which is $1.0184\text{E}10^{-7}$, the environmental carrying capacity (K) is estimated at 3,045,995 tons. The approximated standard error and t statistics of K are 788,004.5 tons and 3.97, respectively, so that the p-value is approximately 0.0003. Since MSY equals ($rK/4$), and the resource stock of the offshore fisheries at MSY equals ($K/2$), MSY and fisheries resource stock at MSY can be estimated to be 236,221 tons and 1,522,977 tons, respectively.

When using 1993 values for technological efficiency, the predicted required vessel tonnage at MSY is 100,800 vessel tons. Comparing this to the actual vessel tonnage for 1993, which was 164,447 vessel tons, suggests that Taiwan's offshore fisheries are currently overcapitalized.

The optimal number of fishing vessels will change as technological efficiency changes. By substituting MSY ($rK/4$) for the current harvest level, Y_t, in the generalized harvest function, equation (1), we can define a compound effort coefficient (e), where $e = A_t^q E_t^{\alpha}$, which is an index of vessel catching power under different levels

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[8] The intercept was excluded because the likelihood ratio test was not significant under the null hypotheses of including the intercept.

[9] Omitting the logged average vessel horsepower variable, A_t, in equation (5) would result in the rejection of the likelihood ratio test H_0: $b_0 = 0$.

[10] The root-mean-square percentage errors (RMSPE) measure is computed as:

$$RMPSE = \left\{\left(\frac{1}{T}\right)\sum_{t=1}^{T}\left[(YS_t - YA_t)/YA_t\right]^2\right\}^{1/2}$$

where YS_t is the simulated value of endogenous variable Y, YA_t is the actual historic value for endogenous variable Y, and T is the number of periods in the simulation.

Table 2
Estimates of a Generalized Production Function of Offshore Fisheries in Taiwan

Parameters	Estimates	Asy. Std. Error	t-value	p-value
α	0.5221	0.2121	2.46	0.0189*
β	0.7937	0.0554	14.33	0.0001*
r	0.3102	0.0831	3.73	0.0007*
r/K	1.0184E–7	5.132E–8	1.98	0.0551*
q	0.0828	0.2166	0.38	0.7044
No. of Obs. = 40	Log-Likelihood = 49.57	$\sigma^2 = 0.0056$	$R^2 = 0.9849$	Adj. $R^2 = 0.9832$

Note: * Significance under the 5% level.

of technological efficiency. At MSY, $e = 2.952$. When the actual compound effort coefficient for each year is compared with this ideal value, 1973 emerges as the year that actual harvest was equal to MSY. In addition, simulation of the stock of Taiwan's offshore fisheries for the past 20 years indicates a clear and steady decline since then.

Estimating Maximum Economic Yield and Optimal Yield

Suppose that the offshore industry net benefit is specified as:

$$\Pi(X_t, Y_t) = R(X_t, Y_t) - C(X_t, Y_t) \tag{6}$$

where $\Pi(X_t, Y_t)$ is the offshore industry net benefit in period t; $R(X_t, Y_t)$ is the revenue function $p \cdot Y_t$; $C(X_t, Y_t)$ is the cost function; $c \cdot E_t$; p is the weighted average harvest price (NT$/kg); and c is the average cost per unit of fishing effort (NT$/vessel ton). Note that by assuming the stability of price, p, the dynamic movement of price is not specified in the current optimization problem. Then, the industry net benefit function is defined as:

$$\Pi(X_t, E_t) = p \cdot H(X_t, E_t) - c \cdot E_t \tag{7}$$

and the short-run net benefit function is defined as:

$$\Pi_S(X_t, E_t) = p \cdot H(X_t, E_t) - vc \cdot E_t \tag{8}$$

where vc is the variable cost of fishing effort.

Suppose the discount rate is represented by δ, and the discrete time discount factor, ρ, equals $[1/(1 + \delta)]$. The problem of maximizing total industry net benefit across time with respect to X_t and Y_t is then defined as:

$$\max \sum_{t=0}^{T} \rho^t \prod (X_t, Y_t)$$

which is subject to the generalized harvest function as defined by equation (1) and the fisheries growth function. This is specified in the same way as the logistic growth function that comprises the first term in equation (2).

Now the problem of maximizing industry net benefits over time becomes:

$$\max \sum_{t=0}^{T} \rho^t \left\{ pH(X_t, E_t) - cE_t \right\} \tag{9}$$

$$\text{s.t.} \quad X_{t+1} - X_t = G(X_t) - H(X_t, E_t)$$

$$X(0) = X_0$$

with a current value Hamiltonian as defined by:

$$\tilde{H}(X_t, Y_t; u) = \Pi(X_t, Y_t) + u[G(X_t) - Y_t] \tag{10}$$

where u is the shadow price which represents the marginal return of the slackness of the resource constraint.

Under a steady-state equilibrium, the first order conditions of the optimal yield solution, X_{OY} and E_{OY}, are defined to satisfy the following two equations:

$$G(X) + \frac{cH_X}{pH_E - c} = \delta \tag{11}$$

and

$$G(X) - H(X, E) = 0 \tag{12}$$

where $G'(X)$, H_X, and H_E are the first partial derivatives of each function, and the weighted average harvest price (p) and the average cost per unit of fishing effort (c) are obtained from table 1. The implicit function which defines X_{OY} and E_{OY} in equations (11) and (12) can be simplified as:

$$f(X, E) = 0 \tag{13}$$

Solving the net industry benefit equation with a discount rate of zero would provide us an estimate of MEY. In this case, the necessary sacrifice of current benefits does not affect the optimization decision because the ultimate gain, no matter how small or how long it is delayed, lasts forever, and, not being discounted, outweighs any current loss (Clark 1990).

A more realistic model would consider the fisheries a capital stock, and, in order to find the OY, a dynamic optimization would be specified in which the discount rate is not equal to zero. Conrad and Clark (1987) point out that the definition of MSY ignores the social and economic reasons for maintaining fisheries resources, and that MEY criterion ignores time preference; *i.e.*, in reality the discount rate is not equal to zero (Clark 1985; 1990).

Since the estimate of resource stock at OY depends on the discount rate and other economic and biological parameters of the optimal problem, it may be greater or less than that at MSY. However, a "most-rapid" approach policy would drive the stock to the optimal level as rapidly as possible and would sacrifice current production, potentially ignoring the welfare or employment opportunities of fishermen.

In practice, an analysis of the profit structure of the offshore fisheries indicates that the average product price and average cost are 66.30 NT$/kg and NT$98,522/vessel ton, respectively (table 1). If the level of technological efficiency is held constant at the 1993 level, then estimates of fisheries harvest,

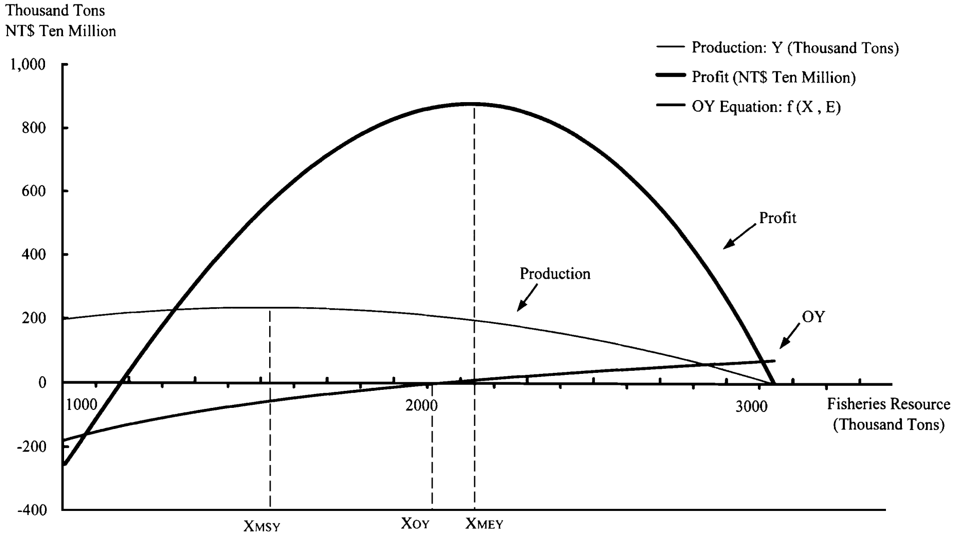

Figure 1. Estimates of MSY, MEY, and OY of the Offshore Fisheries in Taiwan

fishing effort, and resource stock level at OY can be obtained from the implicit function theorem by simulating X_t and E_t nonlinearly to satisfy equation (13).[11] Assuming a 0% or 10% discount rate, the MEY and OY are plotted in figure 1 and detailed in table 3.

The relationship between fisheries resource stock, fishing effort, and fisheries harvest under the MSY, MEY, and OY is as follows:

$$X_{MSY} < X_{OY} < X_{MEY} \tag{14}$$

$$E_{MSY} > E_{OY} > E_{MEY} \tag{15}$$

and

$$Y_{MSY} > Y_{OY} > Y_{MEY} \tag{16}$$

Of the three simulated scenarios above, MEY provides the highest profit, NT$8.9 billion. The actual aggregate profit using 1993 figures shows a deficit of NT$2.9 billion (table 3).

The fisheries resource stock at MEY is 2,132,991 tons, which is greater than that at MSY. However, the level of fishing effort at MEY is 43,012 tons, which is lower than that under MSY. The fact that the MEY harvest level is almost equal to the actual harvest reported for 1993 suggests that by reducing fishing effort to the MEY level, offshore fisheries harvests could be maintained at close to current harvest levels, but aggregate profit would be significantly improved due to increased fisheries stock, decreased fishing effort, and decreased total cost.

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[11] Using a grid search conducted under the GAUSS statistics program.

Table 3
Comparison of the Estimates of the Offshore Fisheries Production, Vessel Tons, Resource, and Aggregate Profit Under Actual Production in 1993, MSY, OY, and MEY in Taiwan

Estimates	Production in 1993	MSY	OY	MEY
Production (Tons)	201,157	236,221	209,238	197,569
Vessel Tons (Tons)	164,447	100,800	51,742	43,012
Resource (Tons)	900,991	1,522,977	2,029,991	2,132,991
Profit (NT$1,000)	–2,865,944	5,735,164	8,773,708	8,860,209

Policy Simulations

In this section, an evaluation of the effectiveness of the vessel retirement and buy back program is provided (Department of Agriculture and Forestry 1993). This program was in effect from 1991 to 1993. Vessels that were over fifteen years old were purchased at prices higher than their scrap value. In addition, simulation of several long-run equilibrium vessel reduction scenarios is presented.

Evaluation of the Effectiveness of the Vessel Retirement and Buy Back Program

In 1991, the government began restricting the building of new vessels. A simulation of the impact on offshore fisheries harvests of the program to restrict the building of new vessels, with or without the vessel retirement and buy back program, is evaluated from the simulations as follows:

Scenario 1. If the government did not apply the vessel retirement and buy back program in 1991, fisheries harvests for the following years could be simulated by assuming that total vessel tons and technological efficiency remained at 1991 levels. This scenario serves as a base case.

Scenario 2. Assume that the government applies the vessel retirement and buy back program from 1991 to 1993. After that time, there is no follow-up program except for a continued restriction on the building of new vessels for an additional ten years.

Both the fisheries stock and fisheries harvests decline steadily under the base case. In the short-term, harvests are lower under *Scenario 2* than *Scenario 1*. Although the second scenario also predicts declining stocks and harvests levels, it is, nevertheless, preferable to the base case because the declines are smaller in the long-term. Neither strategy, however, is sufficient to avoid the downward trend in fisheries harvests and the deteriorating state of the fisheries stock. In addition, the net present value (NPV) of each scenario is reported in table 4. The NPV over time is defined as

$$\sum_{t=0}^{T} \rho^t \prod (X_t, Y_t) = \sum_{t=0}^{T} \frac{1}{(1+\delta)^t} \prod (X_t, Y_t)$$

where the base year is set in 1993, and $\delta = 0.08$. The yearly profit is calculated as total revenue minus total cost, which includes variable and fixed costs. The short-

Table 4
Net Present Value of Profit in Simulations

Simulations	(1) Effectiveness of Vessel Retirement and Buy Back Program (1990 to 2003)		(2) Evaluation of Long-Run Equilibrium Vessel Reduction Scenarios (1993 to 2008)				
Scenarios	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Net Present Value of Profit[1] over Respective Years[2] (Million NT$)	–62,840	–33,052	18,144	6,316	–1,144	–7,815	–26,705
Net Present Valueof Short-term Profit[3] over Respective Years[1] (Million NT$)	3,562	23,617	48,125	40,034	35,177	30,982	19,177

[1] Profit is calculated as total revenue minus total cost, which includes variable and fixed costs.
[2] Net present value over respective years is defined as $\sum_{t=0}^{T}\rho^t\Pi(X_t, Y_t) = \sum_{t=0}^{T}[1/(1+\delta)^t]\Pi(X_t, Y_t)$, where the base year is set in 1993, and $\delta = 0.08$.
[3] Short-term profit is calculated as total revenue minus variable cost only.

term profit is calculated as total revenue less variable cost only. According to the NPV in the first simulation for 1990 through 2003, *Scenario 2* increases the NPV of profit more than *Scenario 1*. However, under *Scenario 2*, even though the NPV of short-term profit is positive, *Scenario* 2's NPV of profit (long-term) is still negative. Therefore, a passive vessel retirement and buy back program is determined to be an ineffective resource stock recovery program.

Evaluation of Long-run Equilibrium Vessel Reduction Scenarios

Given the current status of the offshore fisheries, it seems prudent to reduce fishing effort to a level equivalent to or below MSY in order to improve stock sustainability. Reducing fishing effort will cause stocks to recover. MSY is a more clear and tangible target than OY. While reducing fishing effort to the MSY level might suffice as an initial vessel-reduction measure, the long-run economic situation would be further improved by an additional reduction of fishing effort to the OY level.

Suppose that starting in 1994, the government implemented a vessel reduction program aimed at maintaining fisheries harvests at MSY levels for the long-run. In addition, suppose that fishing effort and total vessel tonnage was fully adjusted according to government regulations, and that technological efficiency was held at 1993 levels. Five different long-run equilibrium vessel reduction scenarios present themselves:

Scenario 1. Apply a vessel reduction program in 1994 to reduce total vessel tons to 100,800 tons (MSY level) in one year.

Scenario 2. Apply a vessel reduction program in 1994 to reduce total vessel tons to 100,800 tons within five years.

Scenario 3. Apply a vessel reduction program in 1994 to reduce total vessel tons to 100,800 tons within ten years.

Scenario 4. Apply a vessel reduction program in 1994 to reduce total vessel tons to 100,800 tons within fifteen years.

Scenario 5. Hold the total vessel tonnage at the 1993 level (the base scenario).

Simulation results show that, except for *Scenario 5*, all other scenarios predict a steady increase in the fisheries stock. The first, second, and third scenarios result in a sharp drop in fisheries harvests. However, fisheries harvests under these scenarios increase later. The fourth and the fifth scenarios, on the other hand, result in a steady decline of fisheries harvests over the next fifteen years. The net present value (NPV) of each scenario is reported in table 4, and *Scenario 1* is the most profitable.

The substitutability between offshore harvest and imported fish is quite high in Taiwan. Whenever domestic prices increase, foreign imports increase, thus price stabilizes. Therefore, the price for fish in Taiwan is quite stable even though there might be a serious reduction in harvest of offshore fisheries in the future. In practical terms, attaining MSY within five to ten years, *Scenarios 2 and 3*, is preferable over the one-year approach, *Scenario 1*, because harvest reductions would be less severe in the first five to ten years.[12] In addition, offshore fisheries stock declines are prevented. Implementing the program over ten years, *Scenarios 4 and 5*, will not provide an effective solution.

Conclusions

This study compares the harvest capacity of Taiwan's offshore fishing fleet to sustainable yields of these offshore fisheries and evaluates different legislative strategies designed to reduce fishing fleets. First, aggregate fisheries stock dynamics and harvest functions are specified and estimated by using yearly harvest and fishing effort data from 1953 to 1993. Results show that the offshore fisheries stock in Taiwan starts to decline in 1973, and that the offshore fisheries are overharvested. The actual harvest level in 1993 is less than estimates of MSY and OY, but higher than MEY. The estimate of fisheries stock under the MSY level is less than stock under the OY level, and the estimate of effort under the MSY level is greater than effort under the OY level.

Based on dynamic simulations, this study evaluates the impact of alternative vessel-reduction policies. The results determined by this study can provide government agencies with predictions of the impact of alternative regulations concerning the number of fishing vessels, while taking into account both stock abundance and economic conditions. This study also concludes that neither the program to restrict the building of new vessels nor a combination of this program with the vessel retirement and buy back program is sufficient to avoid a downward trend in fisheries harvests or to allow for the recovery of declining fish stocks.

Given the current status of Taiwan's offshore fisheries, a reduction in fishing effort will lead to the recovery of fish stocks. The MSY is a clear and manageable target that needs to be reached before pursuing OY. While MSY might suffice as an initial vessel reduction target, the long-run economic condition of the fishing industry would be further improved by reducing fishing effort to the OY level. Attaining MSY within five to ten years is preferable over a one-year approach, because harvest reductions would be less severe and the decline of offshore fisheries stocks would still be prevented.

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[12] In the short-run, severe harvest reductions represent unemployment of offshore fishermen by assuming the average price of fish is stable.

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