EVALUATION AND SIMULATION OF FISHING CAPACITY AND BACKWARD-BENDING SUPPLY OF THE OFFSHORE FISHERY IN TAIWAN

Chin-Hwa Sun, Institute of Applied Economics, National Taiwan Ocean University,
jsun@mail.ntou.edu.tw

ABSTRACT

In 2002, the offshore and coastal fisheries only account for 19.9% and 7.3%, respectively, of the total landing value. Since 1978, the offshore harvests follows a downward trend, but the number of fishing vessels, the total vessel tonnage, and the total horsepower of vessels follow an steady increasing trend until 1992 when the overall restriction on the construction of fishing vessels was imposed.

In order to maintain the sustainability of Taiwan's offshore fisheries stocks and to avoid overfishing, the government has implemented a fisheries management policy which regulates harvests by suspending fishing licenses, restricting construction of fishing vessels, and buying back used vessels in order to reduce the offshore fleet size. The most recent measure, announced on Dec. 24, 1991, which is still in effect, restricts the construction of all fishing vessels, except for fish transport vessels over 2,000 tons. In addition, the government adopted two voluntary vessel buy back programs in order to reduce the fleet size in 1991-1995 and 2000-2004, respectively.

This study tries to examine whether or not the current offshore fishing industry in Taiwan falls in a Pareto inferior situation with smaller output and higher price, such as shown in the upper part of the backward bending supply. By using annual offshore fisheries harvest and the total tonnage and horse power of fishing vessels for the period 1953 to 2002, this paper utilize the bioeconomic model present in Sun (1998) to simulate the backward bending supply curve under various fishing capacity. A suggestion will also be provided to show how to reduce the fishing effort to meet the goals of conservation and the viability of the fishing industry.

Keywords: overfishing, voluntary vessel buy back programs, backward bending supply curve, offshore fisheries in Taiwan

INTRODUCTION

Since 1978, the offshore harvests follows a downward trend, but the number of fishing vessels, the total vessel tonnage, and the total horsepower of vessels follow an steady increasing trend until 1992 when the overall restriction on the construction of fishing vessels was imposed. Such as shown in Figure 1, the offshore harvests, vessel numbers, total vessel tonnage, and total horsepower in 1993, were 5.5, 3.2, 7.8, and 35.2, respectively, times of the level in 1953.

Since the average harvest per vessel ton has followed a decreasing trend after 1963, overcapitalization has become obvious (Sun, 1998). In order to maintain the sustainability of Taiwan's offshore fisheries stocks and to avoid overfishing, the government has implemented a fisheries management policy which regulates harvests by suspending fishing licenses, restricting construction of fishing vessels, and buying back used vessels in order to reduce the offshore fleet size.

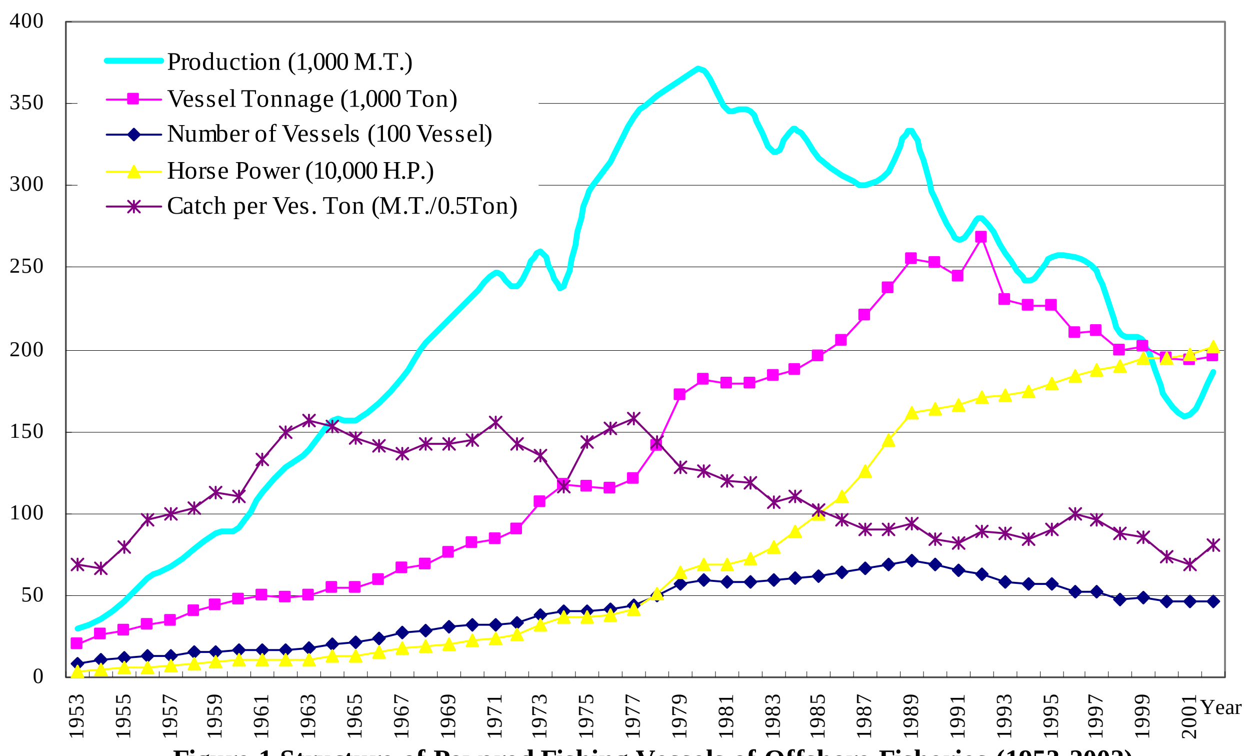

Figure 1 Structure of Powered Fishing Vessels of Offshore Fisheries (1953-2002)

Furthermore, a major revision of the Fisheries Act in 1991 gave the government the explicit right to adjust the fishing effort according to resource abundance. The government could limit the number of vessels, total vessel tonnage, fishing area, fishing period, and design 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.

Four amendments that regulate the number of offshore fishing vessels in Taiwan were enacted in 1967, 1980, 1989, and 1991. 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).

The most recent measure, announced on Dec. 24, 1991, which is still in effect, restricts the construction of all fishing vessels, except for fish transport vessels over 2,000 tons. In addition to the overall restriction on the construction of fishing vessels, the government adopted two voluntary vessel buy back programs in order to reduce the fleet size in 1991-1995 and 2000-2004, respectively. The amount of government expenditure and the number of vessels bought back in each period are shown in Figure 2. Note that 2,319 vessels were bought back during 1991-1995 and the total government expenditure reaches NT$1,721 million (US$52.16 million). The purchase price of the vessel is based on price per gross ton which is around NT$14,552 in 1991-1995.

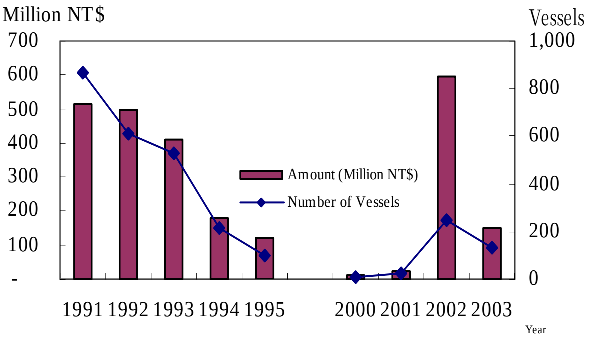

Figure 2 Government Expenditure on Vessel Buyback Program (1991-1995 and 2000-2003)

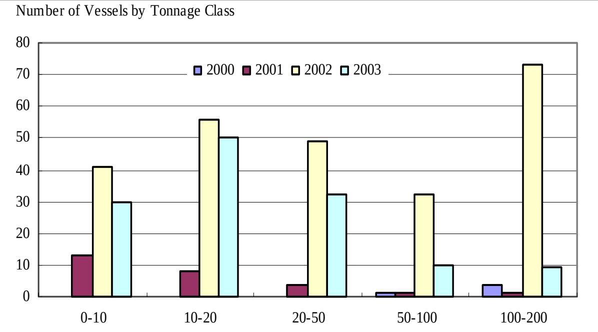

Figure 3 Number of Vessels Bought Back by Tonnage Class in Taiwan (2000-2003)

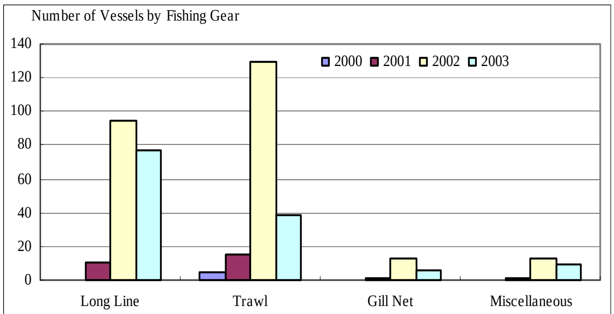

Figure 4 Number of Vessels Bought Back by Fishing Gear in Taiwan (2000-2003)

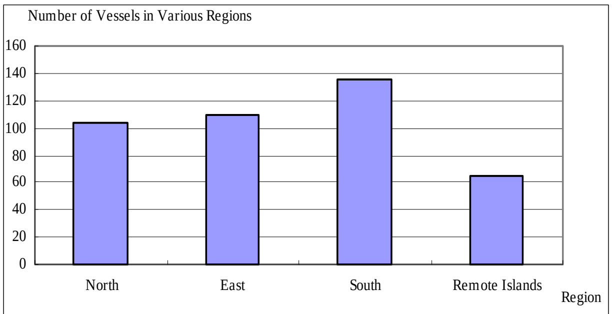

Figure 5 Number of Vessels Bought Back by Region in Taiwan (2000-2003)

By using 1993 values for technological efficiency, Sun (1998) predicted the 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 the fishing capacity is almost 40% overcapitalized. Based on dynamic simulations, Sun (1998) showed that a combination of imposing a ban on the construction of new vessels and the vessel retirement and buyback program in 1991-1995 is not sufficient to avoid the downward trend in harvests and the deteriorating state of stocks.

In Sun's study, an analysis of the profit structure of the offshore fisheries indicates that the average product price and average cost are NT$66.30/kg and NT$98,522/vessel ton, respectively, in 1992. If the level of technological efficiency is held constant at the 1993 level, then estimates of fisheries harvest, fishing effort, and resource stock level at Optimal Yield OY can be obtained from the implicit function theorem by simulating X_t and E_t nonlinearly to satisfy the capital theory in renewable resources[1] (Clark, 1985; 1990) with an 8% discount rate.

Even though the second phase buyback program initiated in 2000 which offers NT$18,000 to buy back the vessel, only 5 vessels accept the offers. Hence, a new scheme in the 2001 buyback program was to set up a scheme to increase the price per gross ton to NT$50,000 for vessels less than 5 gross ton. However, the second stage buyback program implemented in 2001 was still not very successful as fishermen under rational expectation were holding out in waiting for higher payment scheme to be introduced in the near future. Only 28 vessels were bought back in 2001.

This prompted the government to announce a new payment scheme in 2002 designed to speed up the buy back by offering a higher amount in 2002 but the amount would decrease in the subsequent years as follows:

(1) NT$70,000 if purchased in 2002, NT$60,000 in 2003, and NT$50,000 in 2004 for each gross ton for vessels less than 5 tons;
(2) NT$60,000 if purchased in 2002, NT$50,000 in 2003, and NT$40,000 in 2004 for each gross ton for vessels between 6 to 10 vessel ton;
(3) NT$50,000 if purchased in 2002, NT$40,000 in 2003, and NT$30,000 in 2004 for each gross ton for vessels between 11 to 20 vessel ton,
(4) NT$40,000 if purchased in 2002, NT$30,000 in 2003, and NT$20,000 in 2004 for each gross ton for vessels between 21 to 50 vessel ton,
(5) NT$35,000 if purchased in 2002, NT$25,000 in 2003, and NT$20,000 in 2004 for each gross ton for vessels between 51 to 100 vessel ton,
(6) NT$18,000 if purchased in 2002, NT$60,000 in 2003, and NT$50,000 in 2004 for each gross ton for vessels over 100 vessel ton.
(7) The total payment per vessel will not exceed 9.5 million for any vessel purchased, in 2002, NT$8.5 million, in 2003, NT$ and 7.9 million, in 2004.

Note that there are 251 vessels were bought back in 2002 with a total value NT$615 million such as shown in Figure 2. Figure 3, 4 and 5 shown the number of vessels bought back by tonnage class, fishing gear and region in Taiwan.

It is interesting to know the 2002 buyback program was successful to attract all vessels in various tonnage classes and most of them were long line and trawl fishery. However, will the

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

vessel buy-back program improve the stock abundance in 2002 comparing to the status before the program in 1990?

By using the annual offshore fisheries harvest and the total tonnage and horse power of fishing vessels for the period 1953 to 2002, this paper utilize the bioeconomic model present in Sun (1998) to examine whether or not the offshore harvest in 2002 falls in a Pareto inferior situation than before the vessel buy-back program was issued in 1991 with less output under higher demand price, such as shown in Copes's study (1970) that situated in the upper part of the backward bending supply curve of the fishing industry.

ECONOMIC PERFORMANCE OF OFFSHORE FISHERIES AND AQUACULTURE

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 are mostly 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.

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, 2001). 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:

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

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 represented 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 2002, the percentages of total vessel tonnage for the five tonnage classes were 2.94%, 4.38%, 11.05%, 35.32%, and 46.31%, respectively (Table 1). The average harvest per vessel ton was 1,726 kg, and the average harvest value per vessel ton was NT$117,883. When factoring out the cost of equipment, depreciation and interest cost of capital, the average cost per vessel ton was NT$105,991 and the short-term variable cost[2] was NT$83,709.

[2] 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.

The revenue/cost ratio for each of the five tonnage classes ranges from 1.08 to 1.32, with a weighted average of 1.14. 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. 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 1.34 to 1.91, with a weighted average of 1.40. 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.

MODEL SPECIFICATION

By using annual offshore fisheries harvest and aggregate data on fishing vessels for the period 1953 to 1993, Sun (1998) estimates the harvest capacity of Taiwan's offshore fishing fleet under the maximum sustainable yields and evaluates different legislative strategies designed to reduce the fishing fleet. 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) and the dynamic movement of biomass functions of the offshore fisheries are specified and estimated.

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

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:

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

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

Using (1), a function for the resource stock of the fisheries in period t-1, (X_{t-1}) can be substituted into (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}:

$$X_{h,t} = (1+r)(\frac{Y_{t-1}}{A_{t-1}^{q}E_{t-1}^{\alpha}})^{\frac{1}{\beta}} - \frac{r}{K}(\frac{Y_{t-1}}{A_{t-1}^{q}E_{t-1}^{\alpha}})^{\frac{2}{\beta}} - Y_{t-1} \quad (3)$$

By substituting (3) into (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}:

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

The parameters estimated by Sun (1998) show that the estimated intrinsic growth rate (r) equals 0.3102, the estimate of the environmental carrying capacity (K) is 3,045,995 tons, and q, α, and β are parameters which represent the scale elasticities associated with technological efficiency, fishing effort, and resource stock are equal 0.0828, 0.5221, and 0.7937, respectively.

Without assuming a sustainable harvest to maintain constant biomass, i.e., $X_t - X_{t-1} \neq 0$, the actual harvest will not equal to the growth by restriction, this paper simulate the historical biomass ($X_{h,t}$) and substitute it into equation (1) to simulate the historical harvest ($Y_{h,t}$), i.e., the yield is decided by the harvest function. The historical path of harvest ($Y_{h,t}$) is plotted against the historical equilibrium price without assuming sustainable harvest under various technological efficiency and fishing effort in each year, such as shown as historical harvest path in figure 6.

If the historical biomass ($X_{h,t}$) is substituted into the sustainable growth function, $G(X_{h,t})$, such as defined in equation (2), we can simulate the harvest ($Y_{s,t}$), which is equal to the simulated sustainable growth and is the upper limit if there is a mandatory regulation to maintain the sustainability of the biomass.

In reality, such as shown in Figure 6, the historical harvests are all greater than the simulated sustainable growth under various price schemes in various years after 1971 and the simulation results show that the stock follows the declining trend since then clearly, because there is not enough growth to support the harvest to maintain the biomass unchanged.

SIMULATION OF THE BACKWARD-BENDING SUPPLY CURVE UNDER VARIOUS FISHING CAPACITIES

It is interesting to identify whether the harvest in 2002 under the current market equilibrium price is still economically overfishing. By using the parameter estimated by Sun (1998), we can examine whether or not there exists a backward-bending supply relationship under each year's equilibrium condition.

Under the open access assumption, the profit will be driven to zero and defined as follows,

$$\prod(X_t, Y_t) = p_t Y_t - c_t E_t = 0 \quad (5)$$

then the biomass will be lower to $X_{OA,t}$ such as defined as follows,

$$X_{OA,t} = \left(\frac{c_t}{p_t A_t^q E_t^{\alpha-1}} \right)^{\frac{1}{\beta}} \tag{6}$$

where $\Pi(X_t, Y_t)$ is the offshore industry net benefit in period t; p $\cdot Y_t$ is the revenue function; and c $\cdot E_t$ is the cost function; p is the weighted average harvest price (NT$/kg); and c is the average cost per unit of fishing effort (NT$/vessel ton).

By substituting $X_{OA,t}$ into the growth equation, we can derivate $Y_{OA,t}$ which defined the sustainable harvest level corresponding to various cost and price ratio in various periods and it exhibits the characteristic of the backward-bending supply curve for the fishing capacity in each year, A_t and E_t, as follows,

$$Y_{OA,t} = rX_{OA,t}(1 - \frac{X_{OA,t}}{K}) = r\left(\frac{c_t}{p_t A_t^q E_t^{\alpha-1}} \right)^{\frac{1}{\beta}} (1 - \frac{\left(\frac{c_t}{p_t A_t^q E_t^{\alpha-1}} \right)^{\frac{1}{\beta}}}{K}) \tag{7}$$

For example, during the ith year, the fishing capacity (A_i and E_i) and the cost per unit of effort (c_t) is fixed in that year, there exists a backward-bending harvest schedule corresponding to higher prices. Such as shown in Copes (1970), the backward-bending supply curve reflects the schedule that fishermen's responds to various market prices and the market equilibrium is decided by both the supply and demand schedule.

Based on the average product price the cost per unit of effort (c_t) are 66.30 NT$/kg and NT$98,522/vessel ton, respectively, the equilibrium harvest in 1993 is still situated in the backward-bending potion of the supply curve in figure 6.

Since the average product price is NT$78.84/kg and the average operation cost is NT$105,991 per vessel ton, the price-cost ratio in 2002 is higher than the cost-price ratio in 1993 and there exists even larger pressure to explore the resource which leave less biomass stock as defined in equation (5), i.e., even though the government had adopted two voluntary vessel buy back programs in order to reduce the fleet size during 1991-1995 and 2000-2004, i.e., the bio-economic equilibrium situation in 2002 is even worse than the situation in 1993. The economically overfishing phenomenon would call for the need of a further restricted management scheme to avoid overexploiting the biomass.

Conclusion and Discussion

The government in Taiwan has recently instituted a comprehensive program to remunerate fishermen for voluntarily reducing fishing effort in accordance with the bulletin of "In reward for closing fishery season procedure".

The program has been running since September, 2002 with an annual budget of approximately US$12 million. All kinds of fishing vessels that covers all ocean fisheries in Taiwan with valid fishing licenses, except illegal recreational and over 30 years vessels. The vessels shall have 100 days of fishing activities and sum 120 days of suspending fishing activities in the fiscal year or have 100 days of fishing activities and continue 60 days of suspending fishing activities in the fiscal year.

To date, the program has not been very successful, as the payments offered to fishermen for curbing fishing activities are so low which are not sufficiently attractive and there are only 21% of the vessels are voluntary to fulfill the requirement. One way to make the program work is to restrict it to a few selected fisheries with special environmental and resource considerations. By concentrating on a few fishing activities, the program could be redesigned to provide sufficient incentives to reduce the fishing effort further.

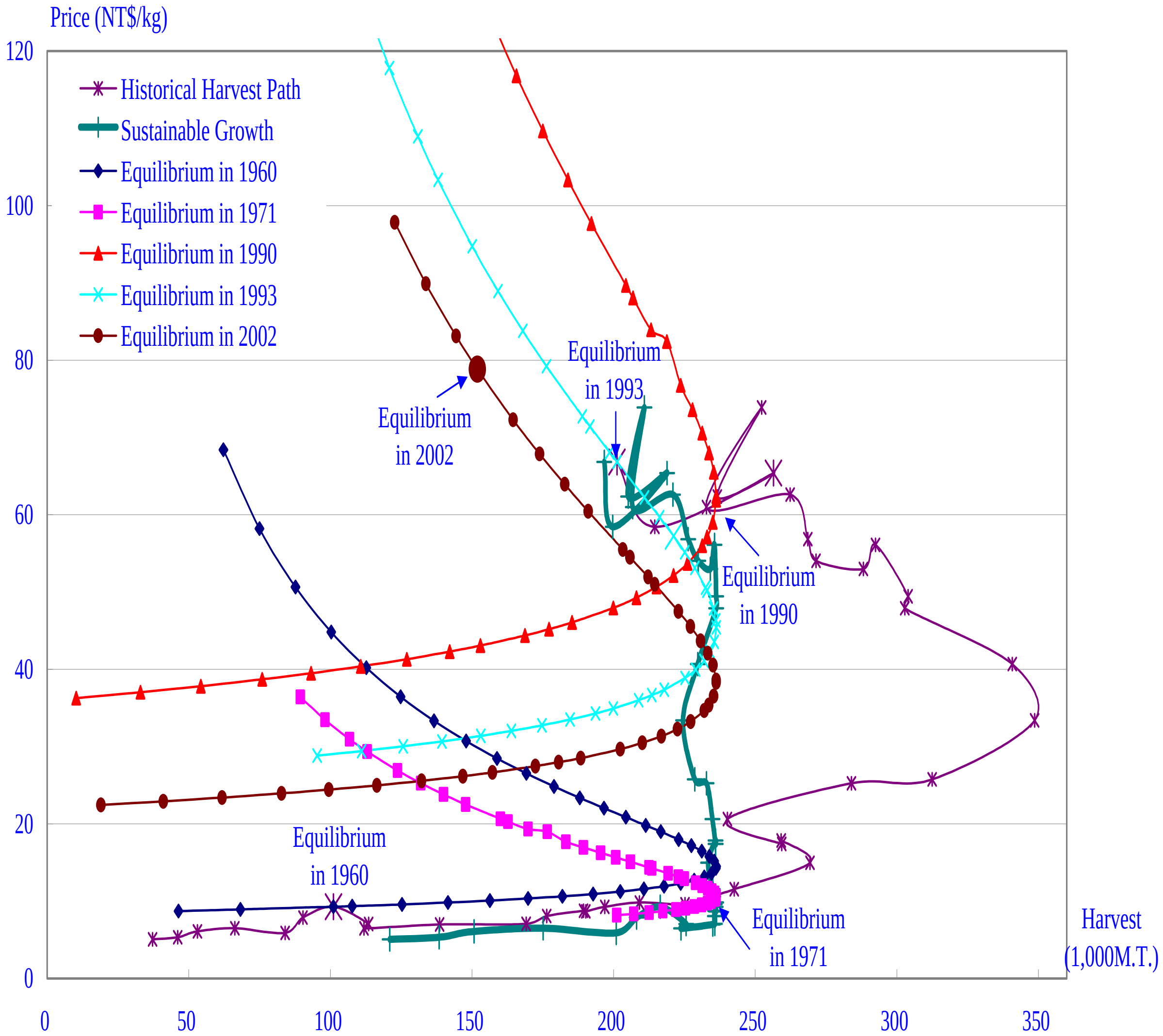

Figure 6 Simulation of the Backward-Bending Supply Curve under Various Offshore Fishing Capacity in Taiwan

REFERENCES

Clark, C.W., 1985, *Bioeconomic Modeling and Fisheries Management*. MD: John Wiley & Sons.

______, 1990, *Mathematical Bioeconomics*. MD: John Wiley & Sons.

Comitini, S., and D.S. Huang, 1967, A Study of Production and Factor Shares in the Halibut Fishing Industry. *Journal of Political Economy* 75:366-72.

Copes, P. 1970, The Backward-Bending Supply Curve of The Fishing Industry, *Political Economy*, p.76-82.

Hannesson, R., 1983, The Bioeconomic Production Function in Fishery: A Theoretical and Empirical Analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 4:968-82.

Sun, C.H., 1998, Optimal Number of Fishing Vessels for Taiwan's Offshore Fisheries: A Comparison of Different Fleet Size Reduction Policies. *Marine Resource Economics* 14:275-88.

Tomkins, J.M., and J.A. Butlin., 1975, Theoretical and Empirical Approach to Fisheries Economics. *American Journal of Agricultural Economics* 26:105-25.

Tsoa, E., W.E. Schrank, and N. Roy, 1984, Generalizing Fisheries Model: An Extension of the Schaefer Analysis. *Canadian Journal of Fisheries and Aquatic Science* 42:44-50.

Taiwan Fisheries Bureau, 1977–1984, *Fishing Vessel Yearbook*, Department of Agriculture and Forestry, Provincial Government of Taiwan, Taiwan: Republic of China. Various Issues.

__,1953-2002, *Fisheries Yearbook in Taiwan Area*. Department of Agriculture and Forestry, Provincial Government of Taiwan, Taiwan: Republic of China. Various Issues.

__, 1992-1994, *Report of the Vessel Retirement Program. Department of Agriculture and Forestry*, Taiwan: Republic of China, Various Issues.

__, 2002, *Annual Economics Survey of Offshore Fisheries and Aquaculture in Taiwan*. Department of Agriculture and Forestry, Taiwan: Republic of China.

Table 1
Offshore Fisheries Production, Revenue, and Cost in Taiwan, 2002

	Average Yield per Vessel Ton (Kg./Ves. Tons) (O)	Average Revenue per Vessel Ton (NT$/Vessel Tons) (A)	Average Cost per Vessel Ton (NT$/Vessel Tons) (B)	Average Variable Cost per Ves. Ton (NT$/Vessel Tons) (C)	Revenue-Cost Ratio (D)	Short Term Revenue-Cost Ratio (E)	Percentage of Total Ton (F)
under 5 Tons	1,506	259,600	196,000	136,000	1.32	1.91	2.94%
5 - 10 Tons	2,276	183,467	157,333	124,667	1.17	1.47	4.38%
10 - 20 Tons	1,342	146,600	134,600	109,200	1.09	1.34	11.05%
20 - 50 Tons	1,612	126,000	116,857	91,371	1.08	1.38	35.32%
50 - 100 Tons	1,867	89,640	80,307	64,587	1.12	1.39	46.31%
Weighted Average	1,726	117,883	105,991	83,709	1.11	1.40	-

[a.] *Annual Economics Survey of Offshore Fisheries and Aquaculture in Taiwan*, 2002, Taiwan Fisheries Bureau.
[b.] $(D_i) = (A_i) / (B_i)$, $(E_i) = (A_i) / (C_i)$
[c.] *Fisheries Yearbook in Taiwan Area*, 2002, 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 approx. 5 - 10 tons; 3 represents vessels approx. 10 - 20 tons; 4 represents vessels approx. 20 - 50 tons; and 5 represents vessels approx. 50 - 100 tons.