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Searching for optimal economic fishing effort for swordfish *(Xiphias gladius)* by Japanese distant water longline fishing vessels

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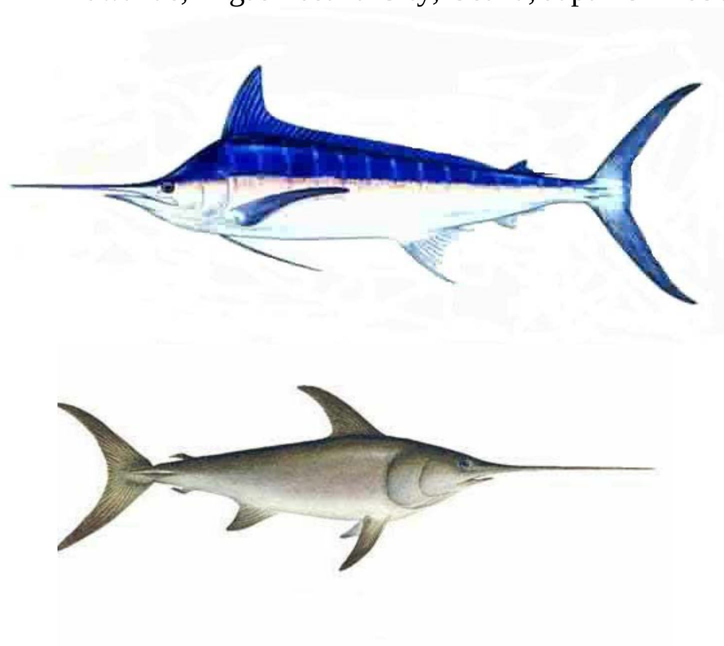

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Searching for optimal economic fishing effort for swordfish (*Xiphiasgladius*) by Japanese off-shore longline fishing vessels

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Abstract

An empirically-estimated landing function for a Japanese off-shore longline fishing vessel is integrated with a demand model for swordfish and operating costs. This integrated model is used to explore optimal fishing efforts to both maximize yields and profits. The simulation explores sensitivities of profits to fuel price and subsidies. The results demonstrate explicit differences between optimizing effort for the maximum landing per trip (45 days per trip) and maximum profits per trip (25 days per trip). As the average days per trip is 41, this result suggests that this group of vessels operates close to the open access equilibrium which is not optimal for the economic maximization. The simulation results suggest, 1) a fuel subsidy increases maximum profit but also the risk of overfishing and 2) an increase in fuel price would lead to lesser maximum profit and a constricted range of efforts for positive profit. The results also demonstrate the possibilities to induce economic reference points for the management of swordfish resources in the North Pacific. While the specific results from this analysis reflect the characteristics of a swordfish fishery by a Japanese off-shore longline fishing vessel, the general conclusions and the modeling approach are applicable for other fishery species under ISC management.

Introduction

The work presented here is of an empirical estimation of the optimal economic fishing effort on the North pacific swordfish stock by off-shore longline fishing vessels based in *Kesennuma* City, Japan.

Fishing effort is often recognized as a key indicator of fisher behavior accessible to fishery managers. It indicates the level of fishing activity on fishery resources, as well as the incurring costs of fishery operations. Fishing effort can be measured in various forms; the size or number of fishing vessels, number of time that fishing gears are applied, and trip days of vessel operations.

The fishery is the economic activity of fishers. The rational individual fisher, therefore, is expected to optimize their fishing effort to maximize the economic benefits from fishing activities by gaining higher revenues at lower costs. To evaluate the economic performance of fishers' activities, it is necessary to incorporate fishing efforts into revenue and cost.

In the longline fishery, two forms of fishing effort, the total number of hooks and days of fishing trip, are often used as indicators of the magnitude of fishing effort. Although the total number of hooks of longline fisheries is often used for the stock assessment with Catch Per unit Effort (CPUE), this type of effort has a challenge to evaluate for cost due to lack of variable cost measures to be converted. Alternatively the total day per fishing trip can be translated as variable costs. Together with the total catch per trip, the days per fishing trip can be applicable to estimate the economic performance of the fishing activity.

By analyzing integrated landings and log-book data from the off-shore longline fisheries based on *Kesennum*, Japan, Ito et al., (2009) demonstrated empirically that the freshness premium, one of the key qualities of landings, is a major determinant of the ex-vessel price of swordfish. The authors suggested that preserving the freshness of already-caught swordfish by decreasing the days of a fishing trip would be one of the strategies to improve economic efficiency for these fishing vessels. In addition, the recent dramatic increase in fuel prices suggests that the additional days in a fishing trip could add to operational costs. Despite the above rational to reduce the days per fishing trips, Ishimura and Yokawa (2009) found that these fishing vessels actually extended the length of their fishing trips from 27.7 days per trip in 1996 to 34.6 days per trip in 2006. The average trip has increased to 41 days per trip during 2008-2010. This contradictory fact would suggest that the optimal economic efforts are not achieved in their operations. These studies reveal ways of improving the economic efficiency of off-shore longline fisheries. However, these studies do not demonstrate the economic performance of the off-shore longline fishing vessel, nor do they analyze the optimal fishing effort to maximize the economic benefits.

This study aims to examine the economic performance of the off-shore longline swordfish fishery and explore the optimal fishing effort needed to maximize the economic benefit from the swordfish stock in the North Pacific. By estimating the harvest function (landings per fishing trip) for an off-shore longline fishing vessel with variable cost per day, and combining this with the price elasticity of swordfish at the *Kesennuma* market, we can determine the optimal efforts to maximize economic benefits. Moreover, we can examine the effects of 1) subsidy for fuel price and 2) fuel price increase.

This study first provides an overview of the off-shore longline fishery based in *Kesennuma*, Japan. In the next section, data analyzed in this study is presented. We follow this with and explanation of the statistical models for demand of swordfish and harvest function. Then, we present the results of the estimations and sensitivity test by considering fuel subsidies and a price increase. Finally, the implications in the light of optimal economic effort are discussed.

Background

Swordfish (*Xiphias gladius)* is one of the most economically valuable billfish species in the North Pacific, for both commercial and recreational fisheries. Targeted (direct) commercial fisheries of swordfish, however, operate in a limited area.

Currently three types of fisheries are engaged in direct swordfish harvest in *Kesennuma*, 1) longline, 2) coastal drift net, and 3) harpoon fisheries. Around 75% of swordfish are landed by the longline fishery (*Kesennuma City*, 2005). Longline fisheries in Japan are licensed commercial fisheries authorized by the Ministry of Agriculture, Forestry and Fishery, and have two categories, 1) distant water (*enyou*) and 2) off-shore (*kinkai*). These categories simply represent holding capacities rather than the distances of fishing operations from shore. Distant water longline fishing vessels have a capacity equal to or greater than 120 MT, and off-shore longline fishing vessels have a capacity of less than 120 MT. In *Kesennuma*, almost all of the active off-shore longline fishing vessels have capacities of 119 MT, which is close to the maximum capacity of the off-shore category. Around 46-53 % of the annual revenue of these off-shore vessels comes from swordfish harvesting (Table 1). While coastal drift net and harpoon fisheries have limited mobility due to the relatively small size of vessels (less than 20 MT), longline vessels have large holding capacities (all vessels 119 MT) and extending operations in fishing grounds in east of the day change line. This paper focuses on the off-shore longline fishery for swordfish.

Materials

Operational and landing data (n=525) of off-shore longline fishery vessels are collected at *Kesennuma* port from 2008 to 2010. In this study, two operational variables are used from this data set for analysis; days per trip and swordfish ladings per trip. For the estimation of the swordfish landing function, only trips for which more than 40% of landing values came from swordfish landings are assumed as swordfish targeting trips and selected for the further analysis (n=338).

The average total trip days for an off-shore longline fishing vessel is 41 days. This can be distinctively divided into three parts (Figure 1); Phase 1) days of traveling for fishing grounds, phase 2) days in fishing operation at the fishing grounds where harvesting takes place and phase 3) days spent returning to port after fishing (Ishimura et al., 2010). On average, these vessels spend 7 days to reach their fishing ground east of the day change line in the North Pacific, engage in fishing activities for multiple days at the fishing ground, then return to the *Kesennuma* for landing by spending another 7 days.

The average annual vessel operating cost data for 2007 and 2009 are provided by Kesenunuma Distant Water Fishery Cooperative (*Kesennuma Enyo Gyogyo Kumiai)*. The variable cost per day and the average number of trip days per year are estimated from these data (Table 2).

Method

This study integrates 1) a demand model for swordfish at the *Kesennuma* fish market and 2) a generalized harvest function model of swordfish fishing.

Demand model

While most tuna species are part of a global market with unlimited substitutions, swordfish forms a unique market; one that exists almost exclusively in *Kesennuma*, Japan. Due to the opportunistic nature of fishing activities and limited target species for this vessel type (i.e., swordfish and blue shark), the vessel allocates effort on either or both swordfish and blue shark seasonally. Therefore, we can assume that off-shore longline fishing vessels are price-takers for swordfish given market demand. As a result, it is reasonable to assume that the price elasticity of demand for swordfish solely defines the ex-vessel price per kg (p). For the demand model, this study applies the monthly landings of swordfish (Y_{month}) from the K*esennuma* fish market.

$$\ln(p_{month}) = a_1 + a_2 \ln(Y_{month}) \quad (1)$$

$$p_{month} = e^{a_1 + a_2 \ln(Y_{month})} \quad (2)$$

Harvest function

A harvest function is applied to estimate the swordfish landings given fishing effort (total days per fishing trip) for an off-shore logline fishing vessel. This harvest function is assumed to be a quadratic relationship between the fishing effort (E_i: days) days per trip i and landing of swordfish per trip i (Y_i: kg) (Anderson 1986, Clark 1990).

$$\begin{cases} \ln Y_i = b_1 \cdot (\ln E_i)^2 + b_2 \cdot \ln E_i + b_3 & E_i > 7 \\ 0 & \text{Otherwise} \end{cases} \quad (3)$$

$$E > 0$$

The first seven days of a trip are for traveling to the fishing grounds and returning from the fihing grounds to the port. This study, therefore, assumes that no yield occurs during this time (Figure 1). From the data, the maximum trip length was 55 days, and 95% of trips were less than 50 days; it is thus likely that the maximum days for trip for this particular type of the longline fishing vessel (i.e., 119 MT capacities) is around 55 days because of the fuel capacity. This implies the maximum days for harvesting activities occur around 48 days.

Note that an implicit assumption of this function is that the landing per fishing effort is independent of the abundance of swordfish. This can be validated because the current stock assessment of North Pacific swordfish suggests that the stock status is a good condition in recent years, much higher than the maximum sustainable level (Brodziak and Ishimura 2010).

Now Y_i is written as

$$Y_i = e^{b_1 \cdot (\ln E_i)^2 + b_2 \cdot \ln E_i + b_3} \qquad (4)$$

<u>Revenue and cost</u>

The total revenue from trip *i* (TR_i) is calculated as the produce of the landing and price

$$TR_i = Y_i \cdot p_i \qquad (5)$$

The total cost per trip *i* (TC_i) is calculated by multiplying E_i and the cost per day operation (c).

$$TC_i = E_i \cdot c \qquad (6)$$

Profit (π_i) is

$$\pi_i = TR_i - TC_i \qquad (7)$$

The average cost for landing (AC) can be induced by dividing TC with landing.

$$AC_i = \frac{TC_i}{Y_i} = \frac{c_i \cdot E_i}{e^{b_1 \cdot (\ln E_i)^2 + b_2 \cdot \ln E_i + b_3}} \qquad (8)$$

The marginal cost per landing (*MC*) can be induced by taking the derivate of TC with respects to landings.

$$E_i = e^{\frac{-b_2 \pm \sqrt{b_2^2 - 4b_1(b_3 - \ln Y_i)}}{2b_1}} \qquad (9)$$

$$MC_i = \frac{dTC_i}{dY_i} = \frac{c \cdot e^{\frac{-b_2 \pm \sqrt{b_2^2 - 4b_1(b_3 - \ln Y_i)}}{2b_1}}}{Y_i \sqrt{b_2^2 - 4 \cdot b_1 \cdot (b_3 - \ln Y_i)}} \qquad (10)$$

Result

Marginal cost per average landing (*MC*), average cost of landing (*AC*) and price per landing (*p*) are illustrated in Figure 2.

The demand model illustrated statistically significant price elasticity the landing if swordfish at the *Kesennuma* port (Table 3). This means that 1% more yield would reduce the ex-vessel price by 0.26%.

All parameter estimations for the yield model are summarized in Table 4. Statistical significance (P-value<0.000) is obtained for all parameters. In addition, the convexity ensures the maximum landing (*MY*). Figure 3 illustrates the harvest function. Landing is maximized at 15.98 MT for 45 days per trip (Table 5). From the data, the maximum trip length was 55 days, and 95% of trips were less than 50 days; it is thus likely that the maximum days for trip for this particular type of the longline fishing vessel (i.e., 119 MT capacities) is around 50 days. The days per trip for the maximum yield would be quite close to the limit of the ability of this particular type of longline fishing fleet.

While the *MY* is obtained by employing a fishing effort of 44.61 days per trip, the days per cruse to maximize profit is less, only 24.94 days, and the maximum profit (*ME*) is $42,540 per trip, with a yield of 12.68 MT (Table 5, Figure 3). Comparing these results, we note that the 45.88 day trip leads to zero profit, which is the fishing efforts for open access equilibrium (E_{OA}) under nonexclusive and competitive fisheries. This implies that the current average days per trip, 41 days, is rather close to the effort at *MY*/open access equilibrium.

Subsidies on fuel cost (or price) is one a major fishery policy used to improve economic operations in fisheries. Figure 4 illustrates the sensitivity of profit per trip when fuel subsidies are considered. High subsidies increase the optimal days per trip for the *ME*, and widen the profitable range of days per trip. This implies that more fishing pressure on swordfish stock is expected upon the introduction of fuel subsidies.

In recent years, most fishing vessel operations are affected by the fluctuation and rapid increase of the cost of fuel. Figure 5 presents changes of profitability under fuel price increases. High fuel prices narrow the range of profitable days per trip. This implies that the economic operation of the off-shore longline vessel would be less stable under fuel price increases.

Concluding remarks

As noted in the introduction, the aim of this study is to investigate economic performance of the off-shore longline swordfish fishery and explore the optimal fishing effort needed to maximize the economic benefit from the swordfish stock in the North Pacific.

As in the seminal work of Gordon (1954), the open access equilibrium occurs under nonexclusive and competitive fishing, and subsequent depletion of the stock. Although our harvest function does not assume the biomass effects on harvest, our study suggests that increase of a variable cost for additional fishing days results quasi-open access equilibrium.

This study suggests that current average fishing effort on North pacific swordfish by the off-shore longline fisheries is not economically optimal, and the reduction of fishing effort (by reducing the days per fishing trip) may bring economic benefits. In addition, the results of this study explicitly illustrate that optimal effort for *ME* differs from *MY*. This implies that utilizing only biological reference points (or catch as a reference point) for management of this fishery would be problematic, and therefore highlights why the economic analysis of fisheries is necessary.

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Table 1: The total annual landing of the off-shore longline fishing vessels in *Kesennuma*.

		2004	2005	2006	2007	2008	2009
Bluefin tuna	Landing(MT)	10.9	7.8	3.7	2.8	2.9	2.9
	Unit ex-vessel price (1000 USD/MT)	23.7	25.8	21.1	20.8	378.2	235.5
	Landing value (1000 USD)	259.3	199.8	78.8	58.4	102.3	63.6
	Species landing share in the value (%)	0.0	0.0	0.0	0.0	0.0	0.0
Bigeye	Landing(MT)	100.5	59.8	40.6	103.7	53.3	75.0
	Unit ex-vessel price (USD/MT)	16.5	20.4	22.7	19.0	192.3	193.0
	Landing value (1000 USD)	1,663.3	1,222.2	920.8	1,971.6	1,077.8	1,292.6
	Species landing share in the value (%)	0.0	0.0	0.0	0.0	0.0	0.0
Small bigeye	Landing (MT)	12.6	5.5	2.3	5.6	3.0	5.5
	Unit ex-vessel price (1000 USD/MT)	7.0	8.2	7.3	9.8	71.5	63.0
	Landing value (1000 USD)	1,659.3	1,037.9	348.6	5,130.0	756.9	934.7
	Species landing share in the value (%)	0.0	0.0	0.0	0.1	0.0	0.0
Swordfish	Landing (MT)	2,010.5	1,748.2	1,726.4	2,223.3	1,842.4	1,677.9
	Unit ex-vessel price (1000 USD/MT)	8.9	10.5	8.5	10.1	119.1	119.2
	Landing value (1000 USD)	17,905.6	18,313.2	14,733.7	22,510.4	17,902.9	16,714.4
	Species landing share in the value (%)	**0.47**	**0.46**	**0.49**	**0.49**	**0.46**	**0.53**
Striped marlin	Landing (MT)	58.5	66.3	59.6	48.4	30.7	17.6
	Unit ex-vessel price (1000 USD/MT)	5.9	6.5	4.9	5.8	104.8	93.3
	Landing value (1000 USD)	345.7	431.3	293.2	280.0	178.4	116.0
	Species landing share in the value (%)	0.0	0.0	0.0	0.0	0.0	0.0
Albacore	Landing (MT)	12.8	13.8	7.3	13.0	7.6	9.8
	Unit ex-vessel price (1000 USD/MT)	3.6	3.7	3.5	2.8	33.5	37.0
	Landing value (1000 USD)	630.7	735.2	368.8	394.9	312.5	437.7
	Species landing share in the value (%)	0.0	0.0	0.0	0.0	0.0	0.0
Blue shark	Landing (MT)	8,278.6	8,774.2	6,148.8	5,785.2	5,644.2	5,106.8
	Unit ex-vessel price (1000 USD/MT)	1.9	2.1	2.2	2.6	39.1	27.4
	Landing value (1000 USD)	15,554.0	18,126.5	13,346.5	15,139.1	18,519.0	11,723.4
	Species landing share in the value (%)	**0.41**	**0.45**	**0.44**	**0.33**	**0.48**	**0.37**
Total	Landing (MT)	11,770.7	12,182.5	8,897.1	9,458.0	8,627.0	7,941.6
	Landing value (1000 USD)	40,468.0	43,504.8	31,435.6	44,207.6	41,114.8	33,012.2
Swordfish+Blue shark	Landing value (1000 USD)	33,459.7	36,439.6	28,080.2	37,649.5	36,421.9	28,437.8
	Species landing share in the value (%)	**0.88**	**0.91**	**0.93**	**0.83**	**0.94**	**0.91**

Table 2: Variable cost per day operation

	Cost per day (USD)	Share in the total variable cost (%)
Fuel cost	1442	47
Bait cost	721	23
Ice cost	72	2
Base crew cost	635	22
Food cost (for crew)	180	6
Total cost	3,101	100

Table 3: Monthly demand function for swordfish.

Variable	Coefficient	Standard Error	*P*-value
Constant	10.063	0.376	0.000
ln (Landing)	-0.262	0.029	0.000
R-sq	0.30		
Observations	189		

Table 4: Swordfish harvest function per trip

Variable	Coefficient	Standard Error	*P*-value
Constant	4.087	0.913	0.000
$\ln(\text{Days})^2$	-0.425	0.095	0.000
ln(Days)	3.083	0.590	0.000
R-sq	0.147		
Observations	338		

Table 5: Harvest, total revenue, total cost and profits at 1) current average days per fishing trip (E_{ave}), 2) days per trip at the maximum landing (E_{MY}), 3) days per trip at the maximum profit (E_{ME}), and 4) days per trip at open access (E_{OA}).

	E_{ave}	E_{MY}	E_{ME}	E_{OA}
Harvest (MT)	15.91	15.98	12.68	15.97
Effort (days)	41.00	44.61	24.94	45.88
Price($USD)	8.92	8.91	9.47	8.91
TR(1000$USD)	141.90	142.35	119.88	142.30
TC(1000$USD)	127.15	138.36	77.34	142.30
Profit (1000$USD)	14.75	4.00	42.54	0.00
E/E_{ME}	1.64	1.78	1.00	1.83

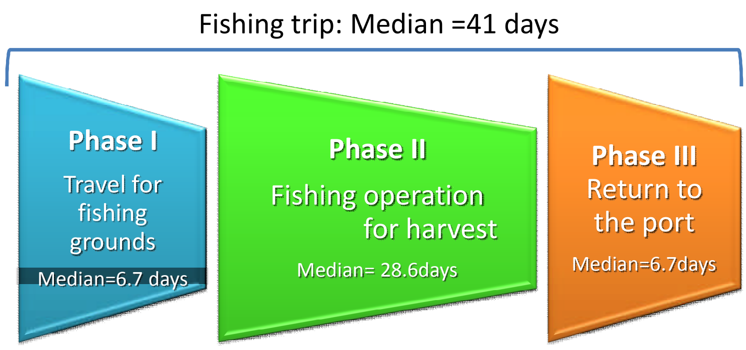

Figure 1: three phases of a fishing trip for the costal longline fisheries in *Kesennuma*.

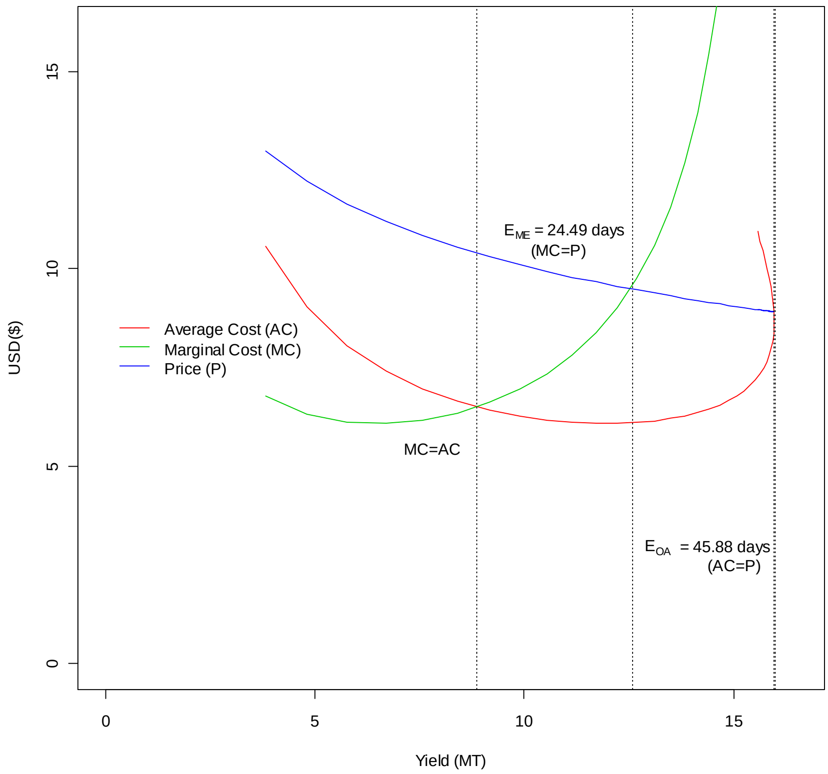

Figure 2: Average cost (*AC*), marginal cost (*MC*) and price (*P*).

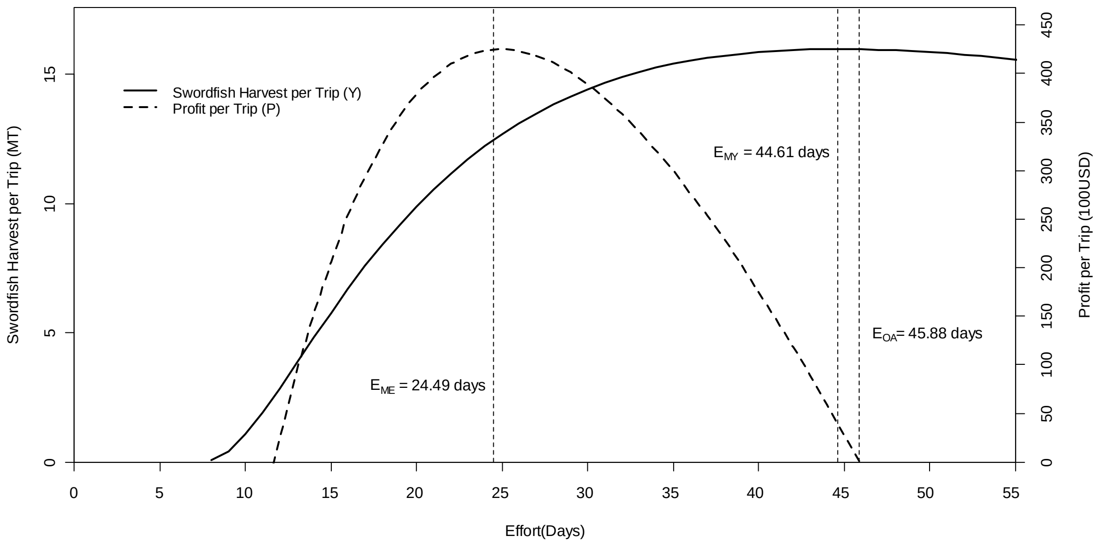

Figure 3: Maximum swordfish landing per trip (*Y*) and profit per trip (*P*) from swordfish landings given efforts (days) per trip.

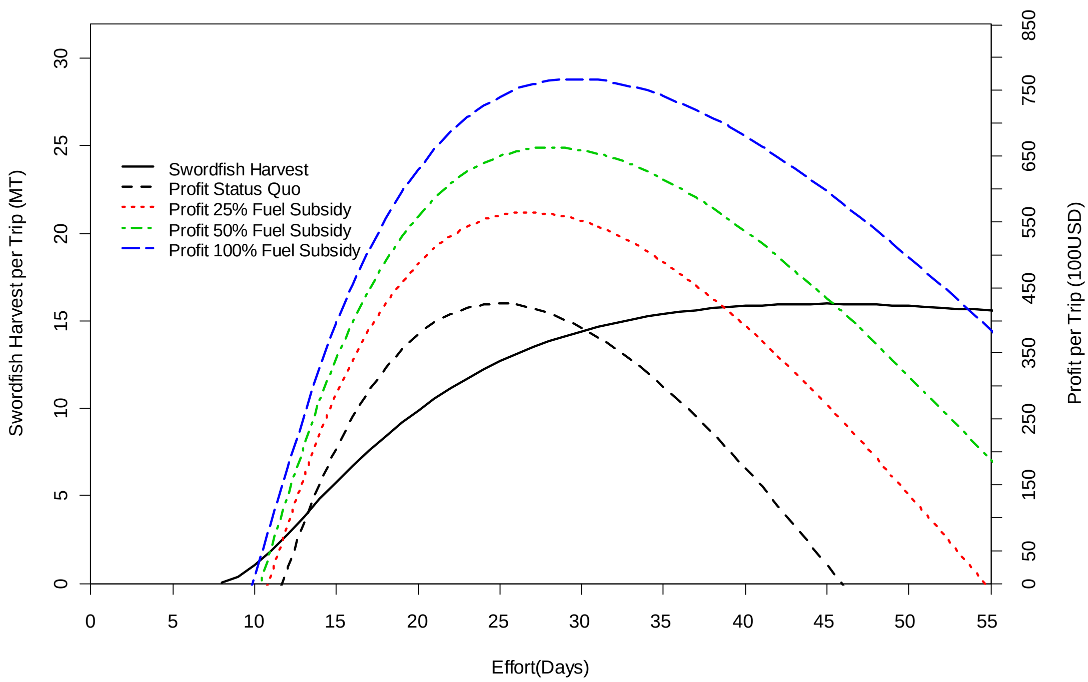

Figure 4: Changes of the maximum profits from swordfish harvest given efforts (days) per trip by fuel subsidies.

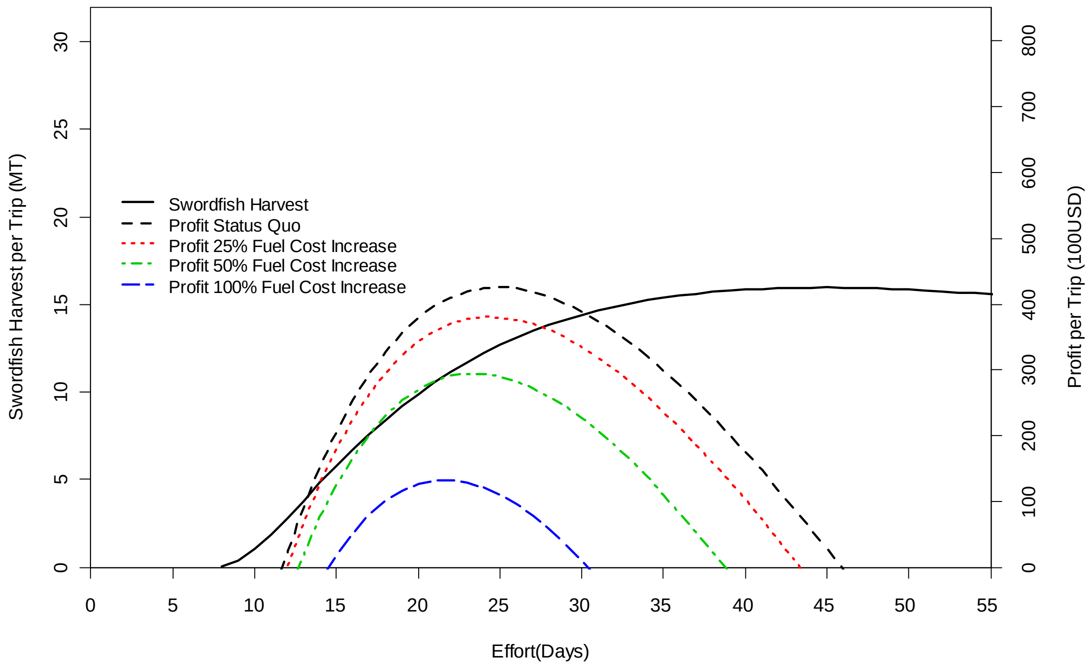

Figure 5: Changes of the maximum profits from swordfish harvests given efforts (days) per trip by fuel price changes.