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Yagi, Michiyuki and Managi, Shunsuke

Graduate School of Environmental Studies, Tohoku University,
Graduate School of Environmental Studies, Tohoku University

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Michiyuki Yagi[1] and Shunsuke Managi[1,2*]

[1] Graduate School of Environmental Studies, Tohoku University, 6-6-20 Aramaki-Aza Aoba, Aoba-Ku, Sendai 980-8579, Japan. Email: yagimichiyuki@gmail.com
[2] Institute for Global Environmental Strategies, Japan. Email: managi.s@gmail.com (* Corresponding Author)

Abstract

Japan's fishery harvest peaked in the late 1980s. To limit the race for fish, each fisherman could be provided with specific catch limits in the form of individual transferable quotas (ITQs). The market for ITQs would also help remove the most inefficient fishers. In this article we estimate the potential cost reduction associated with catch limits, and find that about 300 billion yen or about 3 billion dollars could be saved through the allocation and trading of individual-specific catch shares.

Keywords: Capacity output; Capacity utilization; Individual quotas; Production frontier; Japan

JEL codes: L70; Q18; Q22

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1. Introduction

Excess capacity in fisheries and over-exploitation of fish resources is associated with reduced food production potential and economic waste (Food and Agriculture Organization, 2008a). The race to expand harvesting of wild fish exemplifies the tragedy of the commons and has long been a subject for research in resource economics (i.e., Gordon, 1954). Management of this common-pool resource remains difficult, however, leading to a declining volume of fish caught for developed countries from 1979 through 2005 (FAO, 2008b).

Fisheries in Japan, as in many other countries, are both biologically and economically overexploited (Pascoe et al., 2004). Japanese fishery catches have been decreasing over the last two decades. For example, catches in 2006 totaled about 55,000 metric tons (Fig. 1), which is only 44% of 1987 production (FAO, 2008b). The number of vessels and fishermen has also been diminishing to a 2006 level of 210,246 and 212,470 vessels and fishermen, respectively, down from 308,335 and 411,040 in 1987 (MAFF, 2007). The exit of fishermen has kept labor productivity (i.e., the quantity of fish caught per worker) and capital productivity (i.e., value per fishing vessel) relatively stable for all fish excluding sardines, with a maximum fluctuation of 20%.

Takarada and Managi (2010) describe a negative spiral of overexploitation in the Japanese fishing industry, with a race for fish among fishermen who invest in new capacity to capture as much of the remaining fish stocks as possible. As the fish stock decreased in the late 1980s, these individuals' profits began to diminish. In response, an additional increase in the fishing effort occurred in an attempt to recover previous economic losses. Then, the fish stocks kept decreasing due to further fishing efforts, and the fishermen faced the need to increase their efforts or exit the industry. As a result, the Japanese fishing industry has been shrinking for decades as a market. In fact, the number of the coastal fishing boats and the production numbers for coastal fisheries are decreasing continuously (MAFF, 2005a).

To stop the downward spiral associated with overuse of an open-access resource, fishery policies in Japan include the total allowable catch (TAC) and total allowable effort (TAE) systems, national and prefectural government licensing systems, and a large amount of government financial transfers (GFTs). The TAC is a catch limit set for a particular fishery, generally for a year or a fishing season and is usually expressed in tonnages of live-weight equivalent but is sometimes set in terms of numbers of fish (OECD, 1998). The TAE sets an upper limit on the number of fishing days and the number of operating vessels in a specific area within the exclusive economic zone (EEZ).[1]

For the purpose of resource management, however, these fishery policies need to be further examined. The fisheries in Japan remain open access resources because their TAC caps have been too loose to restrict the activity of fishermen. In most cases, until 2009 in Japan, the TAC caps were higher than the allowable biological catch (ABC) figures, which indicate the level of stock that accounts for the scientific uncertainty in the estimate of overfishing limit. In addition, financial support seems to merely maintain capacity at a stable level rather than attempting to control fishery capacity.

In this article, we analyze the profit potential in Japan's fishery industry that would follow from the allocation of optimal, individually specific catch limits. Keeping in mind the importance of fishery management and production in Japan, this study analyzes the quantitative potential of optimal input/output allocation by assigning optimal individual quotas (IQs). Our results show the ideal case for the potential IQ system in one respect. The catch shares of the IQ system divide the total permitted catch in a fishery into shares (Macinko and Bromley, 2002). That is, under these systems, yearly limits or quotas are set for a fishery.[2] This ensures that, given the scientifically allowable total catch, a percentage share of that total can be allocated to fishermen based on the level of calculated optimal output for each region/fisherman.

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[1] In consideration of the declining fish catches, the Japan Fisheries Agency enacted the "Basic Law on Fisheries Policy" in June 2001. The law presents new guidelines for fishery policy, replacing the "Coastal Fishery and Others Promotion Law" of 1963, whose primary aim was to improve fishery productivity. The Basic Law includes two key concepts: (1) securing a stable supply of fishery products and (2) the sound development of the fisheries industry to promote the appropriate conservation and management of marine life resources.

[2] The allocated shares are bought and sold like shares of stock in a company. Shareholders in the fishery are each guaranteed a percentage of the catch. The number of fish that each fisherman may catch is usually based on past averages. The catch share systems are already common in Australia, New Zealand, and Iceland, while they have been gaining popularity in Canada and the United States. Though our model directly shows how much each individual needs to catch (and use as effort), we do not make a market mechanism a part of the model. In this sense, it is different from the catch shares concept. However, we are able to show optimal individual catch combinations so that total catch is divided into catch shares.

The more in-depth purpose of this study is to measure the fishing capacity of Japan's fisheries. Then, we examine how much cost reduction they can achieve in a well-controlled world using unique disaggregated data covering all areas of Japan. We also aim to determine the optimal inputs/outputs mix of Japanese fisheries given fishery quotas. It is also important to recognize how much capacity will be necessary when the TAC system, which is apparently too loose at present, tightens up as individual transferable quotas (ITQs). This offers criteria for stringent quota enforcement. In addition, we consider technical inefficiencies due to differences in fishery areas and fishing types under different conditions and variant distributions of fish stocks.

Previous research has often aimed to measure the degree of excess capacity among fishing fleets, in terms of capacity output and capacity utilization (CU). Fishing capacity is the maximum amount of fish over a period of time (a year or season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology, whereas capacity output represents the maximum level of production that the fixed inputs are capable of supporting under normal working conditions (see FAO, 2003, 2008a; Färe et al., 1994; Johansen, 1968; Kirkley et al., 2003; Morrison, 1985). CU is the proportion of available capacity that is utilized and is usually defined as the ratio of actual (i.e., current) output to some measure of capacity (i.e., potential) output (see Kirkley et al., 2003; FAO, 2003, 2008a; Morrison, 1985; Nelson, 1989). Therefore, CU is measured on a 0 to 1 scale. When CU is less than 1, one could produce a better catch than the current catch if inputs were fully utilized. In other words, smaller inputs are sufficient (assuming they are fully utilized) to produce a catch of the current size.

In this study, we use the revised Johansen industry model to measure capacity outputs following Kerstens et al. (2006). This model uses two steps involving different linear programming (LP) techniques. First, we measure the capacity output by using output-oriented data envelopment analysis (DEA). Then, we measure the optimal fixed inputs given in certain fishery quotas. Optimal scales for outputs and fixed factor inputs indicate the required total outputs and inputs at the industry level. The calculated loss of efficiency shows the possible reduction in the fixed inputs. The capacity outputs assume variable return to scale (VRS) in our model to be flexible. The production frontier is calculated based on the maximum outputs given current inputs.

The data used in this study come from *the 11th Fishery Census of Japan of 2003* and *the Annual Statistics on Fishery and Fish Culture 2003* by the Ministry of Agriculture, Forestry and Fisheries of Japan. The data sets include each aggregated fishery entity in each municipality and for each marine fishery type in the whole of Japan, and they contain a wealth of data at the whole industrial level. Note it is not clear how much of the fleet has changed since 2003. Furthermore, the census data do not include individual data per vessel. Capacity output and CU in this study are estimated not per vessel as defined in previous studies but instead per municipality per marine fishery type. Our estimation method could be applied to other data, however, and is provided as a MATLAB program together with the Japanese data alongside the online version of this article at the publisher’s website.

2. Background

2.1. Policies in Japan

In 1995, the Japan Fisheries Agency started to reduce the number of fishing vessels and restrictions on fishing area and/or period for some fisheries to ensure the sustainable use of fishery resources. The TAC system has also been implemented. The principal laws are “The Fisheries Law,” the “Living Aquatic Resources Protection Law,” and the “Law Concerning the Conservation and Management of Marine Living Resources.” These principal laws were also amended in keeping with the concept of the “Basic Law on Fisheries Policy.” The central and prefectural governments regulate fishing efforts in terms of fishing methods. The TAC system assigns TAC allocations to each fishery separately but not to individual fishermen. While seven fish species are subject to the TAC system, covering about 30% of total fishing in Japan in 2000, the TAE was established as a system for managing total allowable effort with the amendment of the “Law Concerning Conservation and Management of Marine Living Resources.” The TAE includes curtailing the number of boats, the suspension of operations, and the improvement of fishing gear, among others. However, these regulations are not effective, and the catch has been decreasing continuously. Essentially, the regulations are too loose to control the actual activities of fishermen.

Meanwhile, the amount of GFTs related to fisheries in Japan (JPY 271 billion in 2003), which tends to decline slightly over the past 10 years, is much larger than in most OECD countries (OECD, 2006). The largest portion of GFTs related to fisheries in Japan is allocated to the construction of coastal infrastructure (JPY 203 billion in 2003), i.e., fishing ports and other coastal public facilities, among others. The other forms of financial support provided by Japan to the fishing industry are direct payments for fishery restructuring (JPY 2 billion in 2003), interest subsidies (JPY 3 billion in 2003), which are designed to facilitate the structural adjustment of coastal fisheries under certain conditions, and general services expenditures (JPY 62 billion in 2003; OECD, 2006). The amounts of GFTs providing direct payments for restructuring and interest subsidies are much lower than those for the others. These subsidies apparently are justified because they do not contribute to the increase in fishing capacity.

2.2. Review of methodologies

There have been many studies that have focused on fishing capacity and measured capacity output and CU for decades. The assessment methods for estimating CU can be roughly classified into two groups: parametric methods and nonparametric methods. In one example of the use of parametric methods, Kirkley and Squires (1988) introduce a hedonic cost function approach to estimating the aggregate capital stock and investment in a fishery utilizing limited information. They use vessel acquisition price and vessel characteristics in New England from 1965 to 1981. Although these data have several limitations, the results indicate that the investment in New England fisheries appears to have increased over time. The largest increase in investment occurred in 1979, after the passage of the Magnuson Fisheries Conservation and Management Act of 1976.

Similarly, Asche et al. (2008) adopt a parametric approach that includes cost and profit functions, with survey data for costs and earnings. They investigate potential rents and overcapacity in five case studies in Norway, Sweden, Denmark and the U.K. (countries that use individual vessel quota systems), and in Iceland (a nation that uses the individual transferable quota (ITQ) system).

Based on their cost and earnings data, the actual level of economic profits earned by these fisheries, with the exception of Iceland, was found to be negligible. However, the results show that more than half of the vessels were potentially redundant, and potential economic profits were estimated to be between 22% and 61% of revenue in all case studies.

In another case using parametric approaches, Felthoven and Morrison Paul (2004) develop a multi-output and multi-input stochastic function framework considering changing output compositions at full capacity to estimate capacity output and CU. They use the model to analyze catcher-processor vessels in the Alaskan pollock fishery. The average capacity utilization measure in 2001 ranges from 0.65 for a scenario with the flatfish catch held constant to 1.1 for a scenario assuming unrestricted output composition. The former implies that the pollock catch could increase by about 53% on average with the same level of flatfish landings. The latter suggests that economic optimization over outputs will result in less pollock being caught. The authors also find that for many vessels, there is a divergence between the output price ratio of pollock to flatfish and the marginal rate of transformation (i.e., output trade-offs).

In addition, there are also many studies using nonparametric approaches, usually the DEA approach, to estimate capacity output and CU. Tingley and Pascoe (2005a) estimated the CU of four U.K. fleet segments using the DEA model following Färe et al. (1989, 1994) and examined some factors affecting CU via tobit regression analysis. The results indicate that the average CU of otter trawling vessels, beam trawling vessels, scallop dredging vessels, and gill netting vessels in U.K. fisheries are 0.88, 0.67, 0.78, and 0.70, respectively, and show that they could increase their outputs by 14%, 50%+, 28%, and 43%. The results of the tobit analysis suggest that changes in stock abundance are the main factor affecting CU, although the overall statistical quality of the models was poor.

Based on Färe et al. (2001), Kerstens et al. (2006) have developed a sophisticated variation on the multi-output/input frontier-based short-run Johansen industry model. In the industry model, the capacity of individual fishery entities is utilized by minimizing fixed industry inputs given their total outputs, their capacities, and the current state of the technology and assuming that the variable inputs are allowed to vary and be fully utilized. The authors use the industry model to analyze the capacity outputs of the Danish fleets, analyzing scenarios including tightening quotas, seasonal closure policies, lower and upper bounds, decommissioning schemes, and area closures. The results show that vessel numbers can be reduced by about 14% and the use of fixed inputs by around 15%, depending on the specific objective and the policy mix at a specific Danish fishery. Tingley and Pascoe (2005b) uses an industry adjustment model which is in line with Kerstens et al (2006) to find the effects of introducing ITQs on fleet structure and profitability.

3. Model

3.1. Industry model

Following the revised short-run Johansen model by Kerstens et al. (2006), we compute marine fishery efficiencies in Japan. The conceptual model proceeds via two steps. In the first step, the capacity measures are compared to determine capacity production for each fishery entity at the production frontier. Capacity production is calculated using the output-oriented DEA model assuming strong disposal of inputs and outputs and VRS (see Managi et al. (2004) for intuitive explanation of the DEA). In the second step, individual entity capacities are utilized and fixed industry inputs are minimized given total outputs, capacities, and the current state of the technology. This capacity measure is short-run because it does not assume any change in existing firm-level capacity and because it is a technical rather than an economic capacity notion. Another reason is that it also assumes constant stocks.

The following models are used in this study. The production technology S transforms inputs $x = (x_1, \ldots, x_n) \in R_+^n$ into outputs $u = (u_1, \ldots, u_m) \in R_+^m$ and summarizes the set of all feasible input and output vectors: $S = \{(x, u) \in R_+^{n+m}: x\ can\ produce\ u\}$. Let J be the number of regional units. The n-dimensional input vector x is partitioned into fixed factors (indexed by f) and variable factors (indexed by v): $x = (x_f, x_v)$. To determine the capacity output and CU, a radial output-oriented efficiency measure is computed relative to a frontier technology providing the potential output given the current input use: $E^0(x,y) = max\{\theta: (x,\theta y) \in S\}$.

Boat capacity output is defined as the maximum amount that can be produced per unit of time with existing equipment (assuming that the availability of variable factors of production is not restricted). The term "boat" capacity is used where the term "plant" capacity is used for other industry applications. In the context of fisheries, this definition corresponds to the maximum catch that a vessel can produce if the present technology is fully utilized given the biomass and the age structure of the fish stock under general working conditions. We note that this definition does not measure the capacity output level that can only be realized at a prohibitively high cost of input usage (and that hence will be economically unrealistic). This is because this boat capacity measure does not allow the reallocation of inputs and outputs across firms and implicitly assumes that the production of capacity output is feasible and that the necessary variable inputs are available (Kerstens et al., 2006). The production technology $\hat{S}$ of boat capacity can be represented as follows:

$$\hat{S}^{VRS} = \left\{ (x,u) \in R_+^{N+M}: u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, m = 1,\dots,M;\ \sum_{j=1}^{J} z_j x_{jf} \leq x_{jf}, \right. \\ \left. f = 1,\dots,F;\ \sum_{j=1}^{J} z_j = 1, z_j \geq 0, j = 1,\dots,J \right\} \tag{1}$$

The output-oriented efficiency measure θ_1 is measured using the following LP problem for each decision-making unit (DMU) (region or firm) j (j = 1, 2, ..., J) relative to the set of short-run production possibilities. Here we use most disaggregated regional unit as DMU as j:

$$\max_{\theta_1^j, z_j} \{\theta_1^j: (x, \theta_1^j u) \in \hat{S}^{VRS}\} \tag{2}$$

To be consistent with the boat capacity definition, only the fixed inputs are bounded at their observed level, and the variable inputs in the production model are allowed to vary and be fully utilized. The computed outcome of the model is a scalar θ_1. The θ_1 shows by how much the production of each output in each region can be increased. In particular, capacity output for region k of the mth output is θ_1^{*k} multiplied by actual production, u_{km}. Therefore, capacity utilization based on observed output (subscripted "*oo*") is as follows:

$$CU_{oo}^{k} = \frac{1}{\theta_1^{*k}} \tag{3}$$

This ray CU measure may be biased downward (see Färe et al., 1994). This is because there is no guarantee that the observed outputs are not produced in a technically efficient way. The problem of technically efficient measures is solved when both the variable and the fixed inputs are constrained to their current level. Another technical efficiency measure is obtained by evaluating each region $j = 1, 2, \dots, J$ relative to the production probability set S^{VRS}:

$$S^{VRS} = \left\{ (x,u) \in R_{+}^{N+M} : u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, m = 1, \dots, M; \sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \right.$$
$$\left. n = 1, \dots, N; \sum_{j=1}^{J} z_j = 1, z_j \geq 0, j = 1, \dots, J \right\} \tag{4}$$

The outcome (θ_2) shows by how much production can be increased using technically efficient inputs:

$$\max_{\theta_2^j, z_j} \{\theta_2^j : (x, \theta_1^j u) \in S^{VRS}\} \tag{5}$$

The technically efficient output vector is θ_2 multiplied by the amount of observed production for each output. The unbiased ray measure of capacity utilization (subscripted "*eo*") is calculated as follows:

$$CU_{eo}^{k} = \frac{\theta_2^{*k}}{\theta_1^{*k}} \tag{6}$$

The unbiased measure of capacity is not the technically efficient output. The first measure includes both technical efficiency and capacity utilization effects; while the second measure includes only the technical efficiency effects, thus by dividing them provides the capacity utilization (i.e., it is unbiased) (see Färe et al., 1989; Felthoven and Morrison Paul, 2004; Holland and Lee, 2002).

We focus on reallocating catches between vessels by explicitly allowing improvements in technical efficiency and capacity utilization rates. The model is developed in two steps as follows. An optimal activity vector z^{*k} is provided for region k from model (1), and thus, capacity output and the optimal use of fixed and variable inputs are computed in the first step:

$$u_{km}^{*} = \sum_j z_j^{*k} u_{jm} - s_{jm}^{*k}; x_{kf}^{*} = \sum_j z_j^{*k} x_{jf} + s_{jf}^{*k}; x_{kv}^{*} = \sum_j z_j^{*k} x_{jv} \tag{7}$$

where s_{jm}^{*k} and s_{jf}^{*k} are the optimal surplus and slack variables corresponding to the output and fixed input dimensions, respectively. In a second step, these "optimal" frontier figures (i.e., capacity output and capacity variable and fixed inputs) at the regional level are used as parameters in the industry model. In particular, the industry model minimizes the industry use of fixed inputs radially such that the total production is at least at the current total level (or at a quota level in the model extended later) based on the reallocation of production between regions. Reallocation is allowed based on the frontier production and input usage for each region. In the short term, we assume that current capacities cannot be exceeded at either the regional or the industry level. We define U_m as the industry output level of output m and X_f (X_v) as the aggregate fixed (variable) inputs available to the sector of factor f(v); i.e.,

$$U_m = \sum_j u_{jm}; X_f = \sum_j x_{fj}; X_v = \sum_j x_{vj} \tag{8}$$

The formulation of the multi-output and frontier-based industry model can then be specified as follows:

$$\begin{aligned} &\min_{\theta,w,X_v} \theta \\ &\text{s.t.} \sum_j u_{jm}^{*} w_j \geq U_m, m = 1,\dots,M, \\ &\sum_j x_{fj}^{*} w_j \leq \theta X_f, f = 1,\dots,F, \\ &-X_v + \sum_j x_{vj}^{*} w_j \leq 0, v = 1,\dots,V, \\ &0 \leq w_j \leq 1, \theta \geq 0, j = 1,\dots,J, \end{aligned} \tag{9}$$

where the optimal activity vector w represents a weight assigned to the vessel's peers to estimate its capacity output.

3.2. Extension of industry model

We now turn to the second-stage industry model (9). First, based on the second modification above, the constraints for each output dimension must reflect the fact that production may take place in different areas. That is, there are *M* output constraints (species) for each of the *A* areas:

$$\sum_{j} u_{jma}^{*} w_{ja}^{*} \geq U_{ma}, m = 1,\ldots,M, a = 1,\ldots,A \tag{10}$$

Here, the data in this study are municipality data for each fishery type. Therefore, the optimal activity vector w^* in this study denotes a weight allocated to each municipality to estimate each the capacity both in each fishery and each municipality.

Each region *j* has one area *a* that corresponds to the location of each aggregated entity. The industry consists of fishery entities or vessels fishing in different areas. The constraints for each of the total fixed inputs can be formulated in the most general way in terms of constraints indexed by area:

$$\sum_{j,a} x_{fja}^{*} w_{ja}^{*} \leq \theta X_f, f = 1,\ldots,F. \tag{11}$$

The constraints on the variable inputs are as follows:

$$-X_v + \sum_{j,a} x_{vja}^{*} w_{ja}^{*} \leq 0, v = 1,\ldots,V. \tag{12}$$

To offer a menu of current and potential conservation and distributional policies in fisheries, we add some further refinements to the short-run industry model of Dervaux et al. (2000). Here, we focus on four issues: (i) tightening quotas for each species and (ii) the partial tolerance of technical inefficiencies. (i) We consider setting quotas such as the ITQs for particular species in Japan to illustrate how much capacity is necessary given a certain quota. We simply add the constraint:

$$\sum_{a} U_{ma} = U_m \cdot Q_m,\ m = 1,\ \ 0 \leq Q_m \leq 1 \tag{13}$$

given that the species are indexed by *m*, which is equal to 1 (i.e., the first output). Q_m indicates a quota rate for the *m*th current industry output. In this study, Q_m is incremented by 0.01 from 0 to 1 for the purpose of a sensitivity analysis.

(ii) The frontier nature of the underlying technologies may push things too far so that it is practically impossible to require vessels to immediately adjust to technically efficient production plans.

While technical efficiency is a condition for any social optimum, realistic planning procedures may require tolerating technical inefficiency at some points for informational and political reasons (Peters, 1985).

This can be modeled by adjusting the capacity output, which is part of the second-stage industry model, based on its current observed technical inefficiency and ultimately using an efficiency improvement imperative (α) to correct it (see Kerstens el al., 2006). Of course, technically efficient regions need no such adjustment at present. Therefore, assuming that this correction factor is smaller than or equal to unity (α = 1), the adjustment of the second-stage capacity output could take the following form when technical inefficiency is (partially) accepted:

$$\begin{aligned} &\theta \geq 0, \hat{u}_{jma}^{*} = \frac{u_{jma}^{*}}{max\{1, \alpha\theta_1^{*}\}} \\ &j = 1, \ldots, J, a = 1, \ldots, A \end{aligned} \tag{14}$$

In this research, α is 0.1 or 0.2 for all the entities when technical inefficiency is partially tolerated. When α is set as 0.1 or 0.2, the capacity outputs of all the entities are limited to 10 or 5 times the current output.

We sum up the above-mentioned constraints, and our model can be presented as follows:

$$\begin{aligned} &\min_{\theta, w, X_v} \theta \\ &\text{s.t.} \sum_{j} \hat{u}_{jma}^{*} w_{ja}^{*} \geq U_{ma}, m = 1, \ldots, M, a = 1, \ldots, A \\ &\sum_{j,a} x_{fj}^{*} w_{ja}^{*} \leq \theta X_f, f = 1, \ldots, F \\ &-X_v + \sum_{j,a} x_{vj}^{*} w_{ja}^{*} \leq 0, v = 1, \ldots, V \\ &\sum_{a} U_{ma} = U_m \cdot \ Q_m, m = 1 \\ &\theta \geq 0, \hat{u}_{jma}^{*} = \frac{u_{jma}^{*}}{max\{1, \alpha\theta_1^{*}\}} \\ &j = 1, \ldots, J, a = 1, \ldots, A, \ 0 \leq w_{ja}^{*} \leq 1, 0 \leq Q_m \leq 1. \end{aligned} \tag{15}$$

4. Data and scenarios

4.1. Data

The data used in this study come from *the 11th Fishery Census of Japan of 2003* and *Annual Statistics on Fishery and Fish Culture 2003* by the Ministry of Agriculture, Forestry and Fisheries of Japan. The data set is composed of each aggregated fishery entity per municipality per marine fishery type in Japan. *The 2003 Fishery Census of Japan* was conducted to clarify the structures of fishery production in Japan and to explore the overall background on fisheries, including fishing villages, the marketing and processing industries, and other considerations. The purpose is to develop basic data for fishery policies, including improvements to the structure of fisheries.

Our output data consist of production value data (in Japanese yen) and quantity data. There are nine types of outputs used in this study: total production quantity, all fish, other marine animals, Japanese sardines, Japanese jack mackerel, mackerel, Pacific saury, Alaska pollock, queen crab, and Japanese common squid. The TAC system in Japan applies to all seven of these species. For example, the squid showed a slight decline, although it still remains in a dominant position. The pollock has been on the decline mainly due to the subsequent decrease in the catch on the Bering high seas. Mackerel have also decreased drastically over the years.

There are two variable inputs, labor, and fishing days, and two fixed inputs of gross registered, tons (Grt), and horse power (kilowatt), for aggregated fishery entities in each municipality and for each marine fishery type in Japan. The variable inputs are the number of workers on board at peak times and average fishing days for each aggregated entity. These data effectively cover all of the Japanese fishery entities. In total, 74,728 fishery entities are covered as part of the data set of 7,483 observations. The total product value of these data accounts for 89.3% of the original data in the census. On average, each aggregated fishery entity consists of about 10 entities. We have 39 marine fishery classifications (Table 1). Small whaling, diving fisheries, shellfish collecting, seafood collecting, and other fisheries are excluded because we consider these fisheries to be atypical cases.

We assume that management decisions are provided on the disaggregated regional level, especially models (1) and (4), because their decision making is applied to one particular area and one particular fishery type. Thus, the efficiency of each aggregated fishery entity is evaluated relative to one of the potentially 351 different technologies (nine areas multiplied by thirty-nine marine fishery types). The technologies, which consist of only a few similar observations, may lead to biases in the estimation of boat capacity due to a lack of comparable production units. To avoid downward estimation, we use 10 large classifications and refer to the 10 and 39 fishery classifications as fishery types 1 and 2, respectively (see Table 1). Therefore, there are potentially 90 different technologies being used in fishery type 1 and 351 in type 2. We mainly use fishery type 1 and compare type 1 with type 2 in an unconstrained scenario.

4.2. Scenarios

In each specification, we use several different types of output variables. In the first two specifications, production value and production quantity are used as the output variables, and we compare the two levels of efficiency. Then, we divide the estimated production quantity into three categories, which are (a) TAC species, and the others including (b) fish and (c) the other marine animals. The aim of this division is to set production quotas only for particular TAC species and to compare the efficiency levels of the different groups.

We classify a series of scenarios, systematically testing the effect of additional constraints. The results of several policy-oriented scenarios with various constraints are useful in indicating policy implications. These scenarios are summarized in Table 2. Basic scenario 1 is the basic industry model without any particular constraints and uses fishery type 1. Basic scenario 2 uses fishery type 2 without any particular constraints. The tolerated technical inefficiency scenario allows for technical inefficiency but already imposes improvement imperatives of 1,000% and 500% (thus, $\alpha = 0.1$ and 0.2). We compute the optimal inputs in the industry model, implementing the 100% quota for current outputs (which is, essentially, no quota constraint (i.e., $Q_1 = 1$ in Eq. (13)) at each technical inefficiency value.

We also estimate optimal fishery expenditures at the current 100% quota to understand how much expenditure could be reduced in a reallocated world. We focus on four kinds of expenditure in particular: expenditure on vessels, fishing gears, oil, and wages, which appear to change as the amount of fishery inputs varies. However, we have only the production value data as mentioned above. Therefore, we roughly estimate the fishery expenditures related to marine fishery operations using the production value and the optimal inputs at current 100% quota levels.

We use the number of marine fishery entities and the average fishery income and expenditures by organization type as well as total fishery income for fishery households and the whole of the industry according to *the 11th Fishery Census of Japan of 2003* and *Statistical Survey Report on Fishery Management of 2003* (Table 3). We consider only four kinds of organizations: individuals, including family businesses and independent fishermen; firms; and joint management. These are the categories used to calculate the fishery income and expenditures in the whole industry, while the others are not included because we have no detailed earnings statements for them and the numbers of entities in these fishery organizations is low. We compute the numbers of family businesses and employment operations based on the total fishery income for fishery households, and we estimate the fishery income and expenditures for the whole fishing industry in Japan. Although there is indeed only a small difference between the actual value and the estimated value for total fishery income, the total estimate values for vessels, fishing gear, oil, wages, and cost depreciation are 3.7%, 3.2%, 11.8%, 25.7%, and 8.4% of the total estimated fishery income, respectively.

First, to estimate cost reduction in the scenarios analyzed, we simply multiply the total fishery income of the sample data, 932.2 billion yen, by the fishery expenditure ratios estimated above and the total estimated expenditures on vessels, fishing gear, oil, wages, and cost depreciation in the sample, which amount to 34.1, 29.5, 110.2, 239.2, and 78.2 billion yen, respectively. Then, we assume that the expenditures on vessels and fishing gear are correlated with the efficiency score, i.e., θ in Eq. (15).We also assume that the oil costs are correlated with the optimal use of tonnage multiplied by the number of fishing days at the current 100% quota; i.e., $\sum(w_j^* \cdot x_{f,1}^*) \cdot (w_j^* \cdot x_{v,1}^*)$. Finally, we assume that the wage costs relate to the optimal use of labor multiplied by the number of fishing days at the current 100% quota, i.e., $\sum(w_j^* \cdot x_{v,1}^*) \cdot (w_j^* \cdot x_{v,2}^*)$. To estimate the expenditures, we multiply the estimated expenditure on vessels (which includes the expenses associated with vessels themselves and fishing gear), oil, and wages in the first step by θ, $\frac{\sum w_j^{*2} \cdot x_{f,1}^{*} \cdot x_{v,1}^{*}}{(X_{f,1} \cdot X_{v,1})}$ and $\frac{\sum w_j^{*2} \cdot x_{v,1}^{*} \cdot x_{v,2}^{*}}{(X_{v,1} \cdot X_{v,2})}$, respectively.

5. Empirical results

5.1. Scenario analysis

5.1.1. Current and capacity outputs

Scenarios 1 and 2 show the results achieved by comparing current output and capacity outputs (see Fig. 2). In the figure, the vertical and horizontal axes represent percentages of total production values and fixed inputs, respectively. The results are calculated with LP and show what production *values* fixed inputs can maximally produce based on each scenario. Similarly, Fig. 3 shows what production *quantities* the fixed inputs can maximally produce based on each scenario.

The results indicate that there is large excess capacity in Japanese fisheries. This reflects the fact that fisheries management is in a state of crisis. Because access is almost free, fishing activity is under-priced, and therefore, a huge amount of effort is devoted to fishing. Based on the concept of constant returns to scale, 1% of the total fixed inputs produces 1% of the total outputs, and the path of the current output will be linear. Note that efficiency implies the average efficiency of each scenario if we do not specify otherwise. This is because current output is calculated with LP, which seeks to combine DMUs to minimize a requisite amount of the fixed inputs for a certain amount of output. On the other hand, the more varied the efficiency levels of the aggregated entities are, the more curved the line of capacity outputs becomes because 1% of the total outputs can be produced by less than 1% of the fixed inputs.

Comparing the current outputs of the production values and quantities in Fig. 3, the current output of the production values has a less curved line than that of the quantities. This implies that each DMU determines the amount of fixed inputs depending on expected values rather than expected quantities and that this is legitimate decision making depending on the estimation of income and expenditures for each fishery.

Comparing the capacity outputs of the production values and quantities, the capacity outputs of the production values are smaller than those of the quantities. The difference between these numeric values may result from the varied efficiency levels based on the entities' valid decision-making and cost-benefit considerations.

5.1.2. Capacity outputs

We show two results indicating efficiency levels using the production value data and the quantity data. First, Fig. 4 shows the capacity outputs of production values based on each scenario. Sensitivity analyses are provided by changing the total quota, and in each case, efficiency is computed. The quota is used as the horizontal line in the figure. Here, inefficiency in this figure is defined as a percentage reduction of fixed inputs and is determined by applying Eq. (15). According to the results, efficiency levels based on 100% of production value (i.e., the current level of production) as the total quota are 0.102 in basic scenario 1 and 0.169 in basic scenario 2. In the scenarios at current 100% quotas considering areas of technical inefficiency of up to 10 and 5 times, efficiency scores of 0.156 (0.239) and 0.210 (0.292) emerge in the scenarios using fishery type 1 (type 2), and the efficiency scores decrease by approximately 5% at regular intervals as α varies from 1 to 0.1. Fig. 5 shows the capacity output of computed product quantities based on each scenario. The results show efficiency levels at the 100% quota of 0.072 and 0.130 in basic scenarios 1 and 2, respectively. These scenarios are relatively efficient and similar to those for production value. In the scenarios at the current 100% quotas considering technical inefficiency of up to 10 and 5 times, the efficiency scores 0.96 (0.170) and 0.125 (0.197) emerge in the scenarios using fishery type 1 (type 2), and the efficiency scores decrease by about 2.5% at regular intervals as α drops from 1 to 0.1.

5.1.3. TAC species

We show the results of the sensitive analyses achieved by only imposing a quota on the TAC species as ITQ. Figure 6 shows the result achieved when the total product quantities are separated into two groups: the quantity for all TAC species and that for all non-TAC species. The efficiency scores at a 100% quota are 0.109 and 0.169 in basic scenarios 1 and 2, respectively. In addition, the paths of each scenario curve alongside each other and are approximately parallel. In the scenarios at current 100% quotas considering technical inefficiency of up to 10 and 5 times, the efficiency scores 0.135 (0.205) and 0.168 (0.231) emerge in the scenarios using fishery type 1 (type 2), respectively, and the efficiency scores decline by about 3% at regular intervals as α varies from 1 to 0.1.

Additionally, Fig. 7 shows the results that are achieved when the total product quantities are divided into three categories: the quantities for TAC species, those of other fish, and those for other marine animals. The paths of each scenario are also approximately parallel alongside each other. Efficiency levels at the 100% quota are 0.145 and 0.190 in basic scenarios 1 and 2, respectively. In the scenarios at the current 100% quotas considering technical inefficiency of up to 10 and 5 times, the efficiency scores 0.177 (0.222) and 0.204 (0.246) emerge in the scenarios using fishery type 1 (type 2), respectively.

We also provide the results that are achieved when we impose a quota on each of the six TAC species. First, Fig. 8 shows the results using two categories: (1) the six TAC species and (2) one other species. Given a 100% ITQ quota, the efficiency levels in the scenarios for Japanese sardines, Japanese jack mackerel, and mackerel are 0.086, 0.088, and 0.089, respectively, and the efficiency paths for these species vary slightly as each ITQ quota decreases. At a 100% ITQ quota, efficiency levels in the scenarios for Pacific saury, Alaska pollock, and Japanese common squid are 0.093, 0.099, and 0.099, respectively. The efficiency paths vary more than those for the others as each ITQ quota decreases. The efficiency level of the queen crab fishery is 0.084 at a 100% ITQ quota, and the efficiency path is the lowest found in any of the scenarios.

In contrast, the efficiency of basic scenario 1, which imposes a quota on total quantities of all TAC species, is 0.109 if the current industry quota is used. The score is the most inefficient found in any of the scenarios. This result suggests that there are fewer activity vectors to choose from for the aggregated entities to satisfy the quota for each TAC species. In this case, the quota is imposed only on a certain TAC species, and thus, the other fisheries have the capacity to catch 100% of current output. Therefore, there are fewer options in choosing fixed input factors given that quota imposed on TAC species and the efficiency paths change more horizontally.

Fig. 9 shows the results using each of six TAC species, other fish and other marine animals. Efficiency levels at a 100% quota are 0.109 in the Japanese sardine scenario, 0.110 in the Japanese jack mackerel scenario, 0.112 in the Mackerel scenario, 0.118 in the Pacific saury scenario, 0.117 in the Alaska pollock scenario, 0.108 in the queen crab scenario, 0.139 in the Japanese common squid scenario and 0.145 in the all-TAC-species scenario. The efficiency paths of the Japanese sardine and queen crab scenarios are the lowest, and that of the all-TAC-species scenario is the most inefficient. The same is true for the paths using two variables above. Most scenarios for each TAC species are stationary at less than 60% of each quota.

These varied efficiency levels depend on the selection of outputs. When each output in each category is separated in different model, the efficiency score will become even lower. It is difficult to measure the efficiency of each fishery method because there are many fishery species in the Japanese sea and many fishery methods developed in the same regions. While we can estimate efficiency levels in various detailed cases using more disaggregated categories, it will become difficult to discuss entire fisheries in Japan in doing so. The opposite is also true. Based on the results, the efficiency paths seem to be approximately the same in the different cases; they only vary based on the quota for each TAC species.

In summary, ensuring the current capacity outputs (except for certain TAC species), the fixed inputs can satisfy the capacity outputs for the TAC species. Regarding the capacity output of the total quantity per fishery area in basic scenarios 1 and 2, the most efficient area is the Pacific Ocean in the north. Most areas have excess capacity of more than 100% in basic scenario 2. This result implies that there are fixed inputs that can produce more than twice the current quantities in Japan.

The fisheries with the lowest excess capacity are those for Pacific saury. There are excess capacities of 39.0% and 38.9% for Pacific saury using two variables and three variables as above (fishery type 1). The most inefficient fisheries are those for Japanese common squid, with excess capacities of 212.3% and 205.2%.

5.1.4. Capacity utilization

We estimate the CU_{oo} and CU_{eo} of total production value and quantity in basic scenarios 1 and 2. Table 4 presents simple average CU_{oo} and CU_{eo} figures for the aggregated entities. These are not weighted average values, and they are classified by fishery types 1 and 2. There are significant differences between the values of CU_{oo} and CU_{eo} for the different fishery types.

In the basic scenario 1 using estimated quantity data (specifications 3 and 4), the fisheries with the highest average CU_{oo}, i.e., $CU_{oo} = 1$, are large trawls in East China sea, large and medium surrounding net of one-boat operation catching skipjack and tuna on distant water and two-boats operation with purse seine (fishery type 2: (2), (11) and (14)). In specification 3, the fishery with the lowest average CU_{oo} is anglings (fishery type 1: (10)), and the CU_{oo} is 0.113.

In specification 4, the fisheries with the highest average CU_{eo} (i.e., $CU_{eo} = 1$) are large trawls in the East China Sea, large and medium catching skipjack and tuna in distant waters and off-shore water, two-boat operations with purse seine, and squid angling in distant water (fishery type 2: (2), (11), (12), (14) and (34)). In specification 4, the fishery with the lowest average CU_{eo} is squid angling in coastal water (fishery type 2: (36)); the CU_{eo} is 0.486.

The difference between CU_{eo} and CU_{oo} shows the degree of random variation in catch and technical inefficiency, which is not producing the full potential given the level of both fixed and variable inputs. The fisheries with the lowest differences between CU_{eo} and CU_{oo} (i.e., $CU_{eo} - CU_{oo} = 0$) are distant water trawls, large trawls in the East China Sea, large and medium catching skipjack and tuna in distant water, two-boat operations with purse seine and billfish drift gill nets (fishery type 2: (1), (2), (11), (14) and (19)). The fishery with the greatest difference between the CU_{eo} and CU_{oo} figures is angling (fishery type 1: (10)), and the difference value is 0.459.

5.2. Reducing the number of fishery entities

We compute the amount of non-zero activity vectors w^* from the results above and provide the optimal number of aggregated fishery entities at the current 100% quota for each sea area around Japan. Chosen from all the scenarios using the quantity data from the 7,483 entities in our sample, the optimal total number of fishery entities at a 100% quota are as follows: (1) 1,167 at a minimum in the technically tolerated inefficiency scenario up to 10 times of each current output using one variable output and (2) 2,692 at a maximum in the technically tolerated inefficiency scenario up to 10 times of each current output using the three variable outputs.

On average the optimal total DMU numbers are about 2,000. The values of the activity vectors are almost at upper limits among all the scenarios (i.e., all inputs are utilized).We compute the numbers of fishery entities, which is 74,727 in the overall sample, by multiplying the active vector values and the numbers of entities in each aggregated entity level. The minimum number is 4,974.7 in the basic scenario 1 using the quantities data of one variable output. The maximum number is 21,184.7 in the basic scenario 2 using the production value data allowing technical inefficiency up to five times of each current output.

We note that there are large differences among the optimal sizes of fishery entities in each scenario at 100% quota. On average, however, the optimal size of the current Japanese fisheries fishing the amount of current production value/quantity is about one third of current size. In other words, one third of the current fishery entities are required even if the central government implements fishery policies in the most efficient way.

5.3. The optimal input levels

We compute the optimal input amounts at the current 100% quota for each scenario. In each scenario at the current 100% quota, the optimal input values in gross registered tons and horsepower (kilowatts) are equal to each efficiency score, i.e., θ. In each similar scenario, we set the average optimal fishing days as the simple average $w_j^* \cdot x_{v,1}^*$ among DMUs with $w_j^* \neq 0$ and the optimal number of fishermen as $\sum w_j^* \cdot x_{v,2}^*$.

Under basic scenarios 1 and 2, using the production value data at the 100% quota, the average optimal numbers of fishing days are 113.32% and 112.72% of the current average fishing days spent on board, and the total optimal numbers of fishermen are 35.69% and 43.81% of the current totals, respectively. Under the technical inefficiency scenarios, allowing capacity outputs to be up to

10 and 5 times current outputs using the production quantity data for fishery type 1 (type 2), the average optimal numbers of fishing days are 119.43% (114.81%) and 120.45% (116.50%) of the current average fishing days spent on board, and the total optimal numbers of fishermen are 41.62% (53.83%) and 48.59% (58.45%) the current totals, respectively. In summary, in each scenario at the 100% quota, the optimal numbers of fishermen and the optimal average fishing days are about 40% and 120% of current totals.

Going through the amounts of optimal inputs for each fishery type, we see that the most efficient way of allocating the fishery types is different for specific fishery types. In addition, a fishery type with a large amount of optimal inputs may not be an efficient method itself but may yield large capacity outputs arising from optimal inputs based on the first step, the revised industry model. Relatively large amounts of optimal inputs are needed in types of surrounding nets (4), lift nets (6) and fixed nets (7) among others, and long lines (9) in particular are little utilized.

5.4. Estimates of cost reduction

We compute the fishery expenditures for each scenario in Table 5. Overall, the required costs of vessels, fishing gear, and oil (in our computed cases) are mostly less than about 20% of current costs, and the wages and total costs are mostly about 40% and 30%, respectively. In basic scenario 1 (basic scenario 2), using one output variable for the production value, the necessary costs of vessels and fishing gear, oil, and wages amount to 10.21% (16.93%), 11.99% (19.31%), and 35.26% (44.14%), and the overall costs amount to 25.20% (33.33%), respectively.

The reduction in the total number of fishing vessels represents a large amount of the reduction in the total cost in the long run. These significant potential results are important for policy purposes. In basic scenario 1 (scenario 2), using the production value data, the results imply that the current estimated fishery profit (total 133.3 billion yen) will be increased to 442.2 (408.6) billion yen. In addition, the fishery profits should increase because the cost depreciation related to the fishery operations, which is left out of consideration, should decrease in the long run.

6. Discussion and conclusion

This article examines the capacity output and CU of marine fisheries in Japan. Our results indicate that the maximum level of production that the fixed inputs are capable of supporting under general working conditions (i.e., capacity output) could be more than three times larger than what is currently produced. Estimated CUs vary greatly from one marine fishery to another, but overall fixed inputs could be reduced to one tenth of their current level. Fishery profits could be increased to about three times their current level.

Our results for Japan indicate much greater potential for improvement than Kerstens et al. (2006) found for Denmark. The differences between the two scenarios are caused by the large differences in fishery management level (or efficiency). The creation of profitable and sustainable fisheries requires retiring the most inefficient fishers, through a government-backed industry development program. This study does not discuss the details of input and output control policies. Political factors often favor input-oriented approaches to managing fisheries. However, there appears to be increasing acceptance of output-oriented controls used to manage catches of target fishes (Holland, 2007). Our approach is not market-based but we show the expected outcome of output-oriented controls. For the output-oriented controls to be implemented inexpensively, improvements in remote automated monitoring technology need to increase the feasibility and then diminish the cost of outcome controls.

Our study shows that there are many inefficient fisheries. To help them exit the industry, buyback programs may need to be increased. However, higher government subsidies should be carefully considered before they are implemented. Simple buyback programs that purchase inefficient vessels out of a fishery will not help to solve the overcapacity problem (see Asche et al., 2008; Clark et al., 2005; Holland et al., 1999). First, the buyback programs might at best remove only a marginal portion of the fishing fleets, with less efficient vessels remaining in the fisheries. Secondly, buyback programs will not work properly without other work opportunities for fishermen who leave a fishery. Additionally, incentives remain for vessels to increase their own level of capitalization. Finally, even if the buyback programs were effective, the programs would significantly reduce employment in the fisheries and local communities because there is a close relationship between the number of vessels and the number of fishermen. This development would run counter to social policies concerned with protecting societies along remote coastlines (Asche et al., 2008).

In conclusion, legislating for property rights over fisheries is necessary to stop the downward spiral of this industry. Our approach estimates the optimal cost reduction and profitability that is achievable under Japan's current fishing activity management system, run by central planners. One might also consider potential efficiency in fisheries based on other mechanisms such as individual transferrable quotas (ITQs) (MAFF, 2008). Either way, the potential magnitude of gains demonstrated in this article has important implications for fisheries policy in Japan and elsewhere.

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Supporting Information

Data Appendix Available Online: A data appendix to replicate main results is available in the online version of this article.

https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fj.1574-0862.2010.00533.x&file=AGEC_533_sm_SManagi.zip

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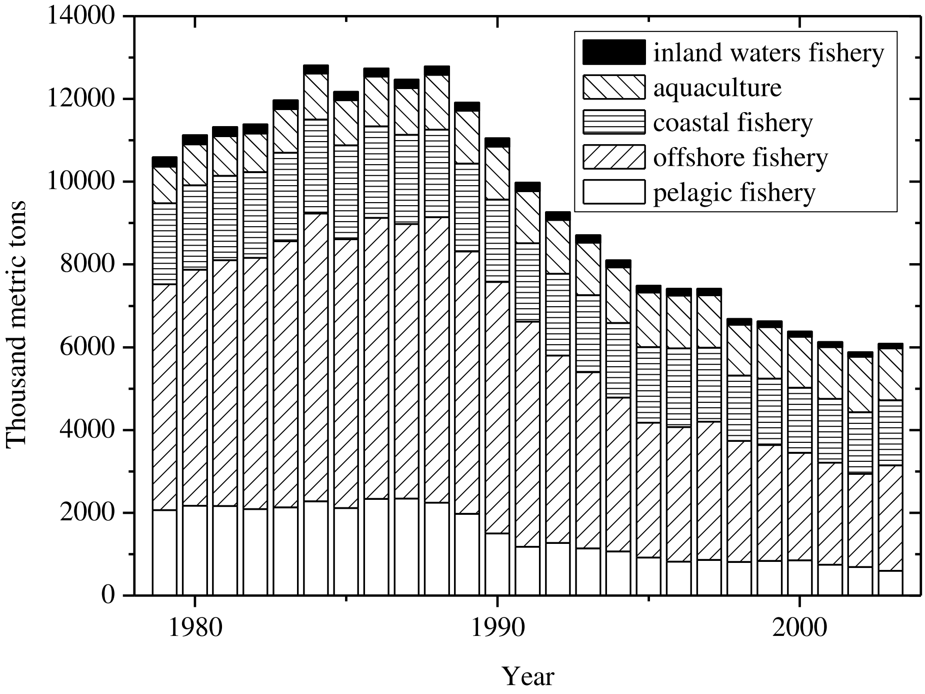

Fig.1 Trend of Fishery Catch in Japan

Source: Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2005b, "*Annual Statistics of Fishery and Fish Culture 2003"*

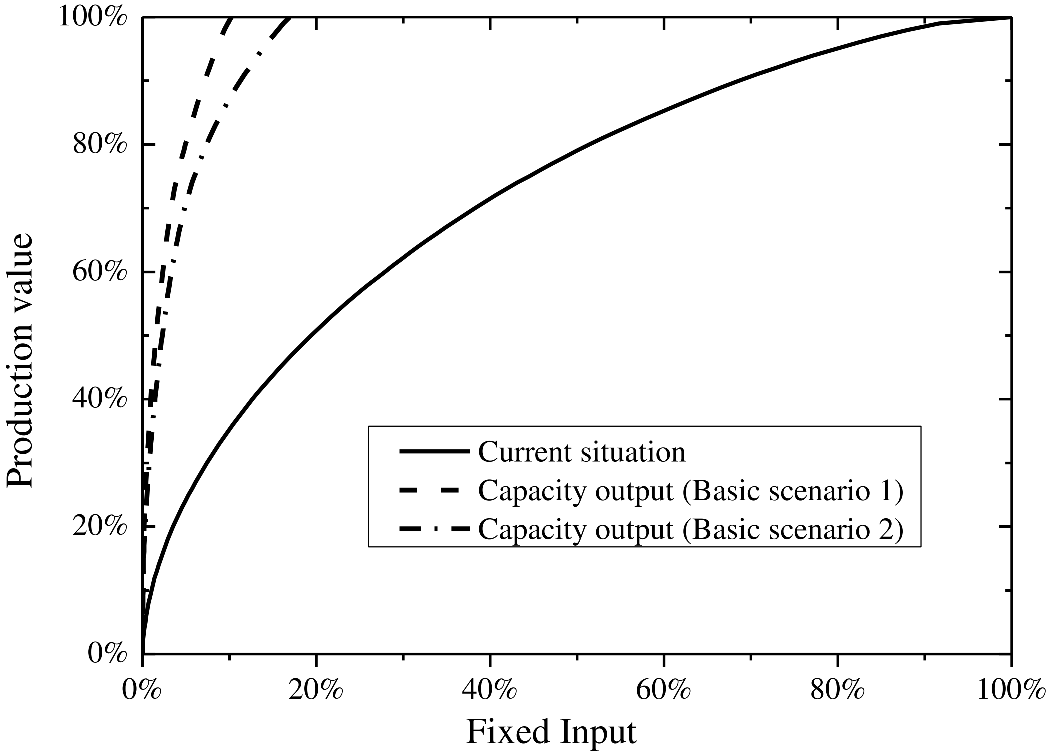

Fig.2. Current and Capacity Output (Catch value)

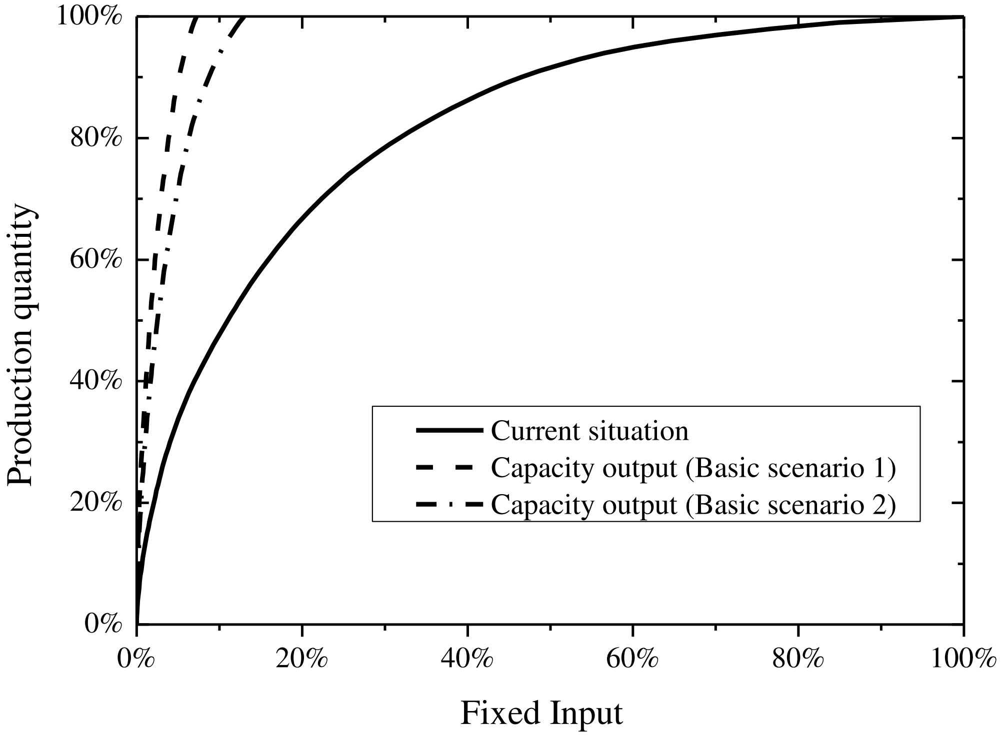

Fig.3. Current and Capacity Output (Catch quantity)

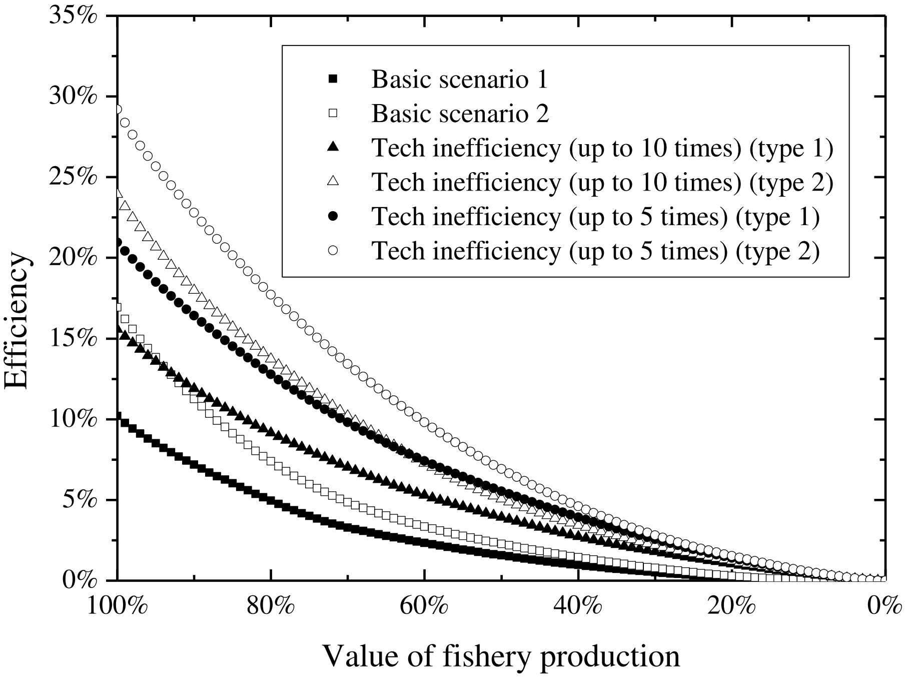

Fig.4. Efficiency Level of Japan's Fishery: Catch Value of Output using Industry Model

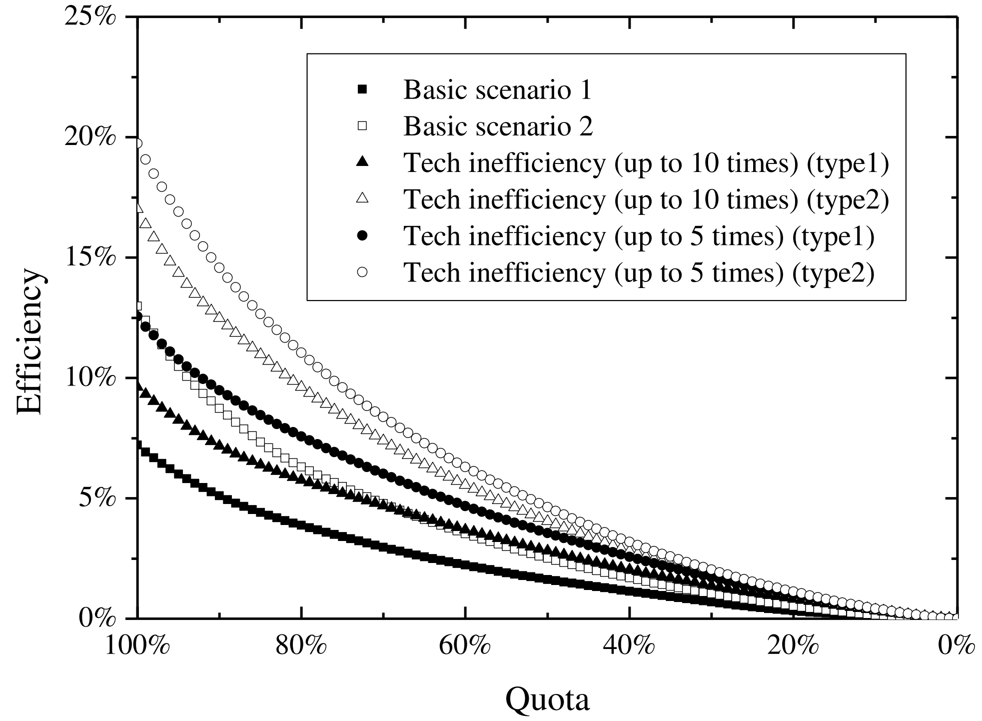

Fig.5. Efficiency Level of Japan’s Fishery: Catch Quantity of Output using Industry Model

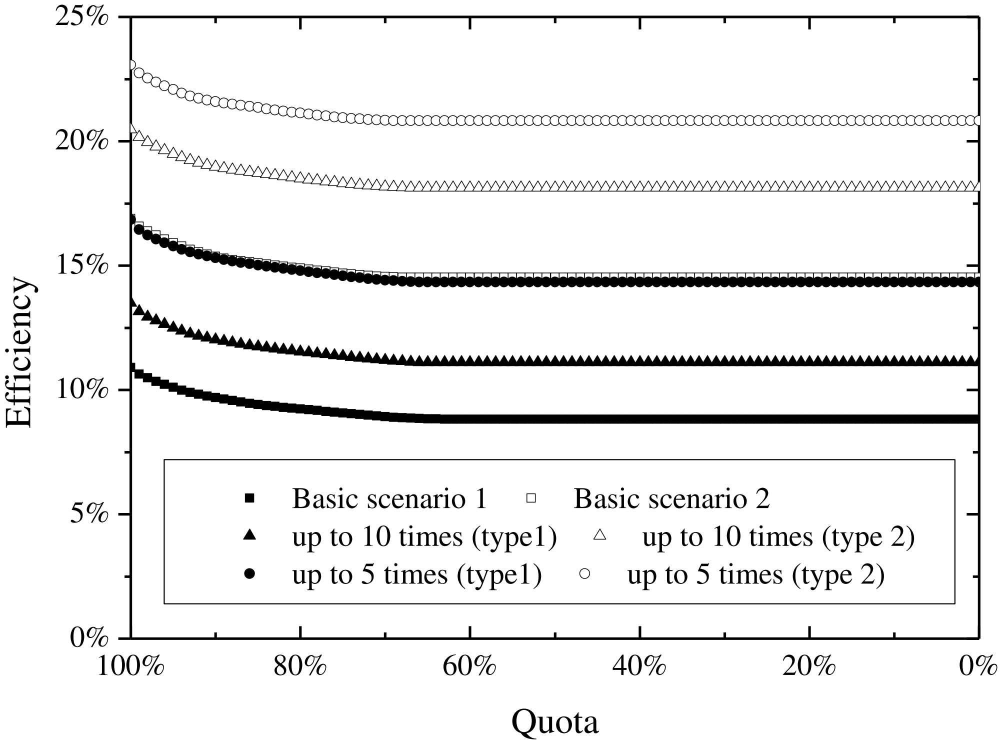

Fig.6. Efficiency Level (Two Outputs Case: TAC and Non-TAC)

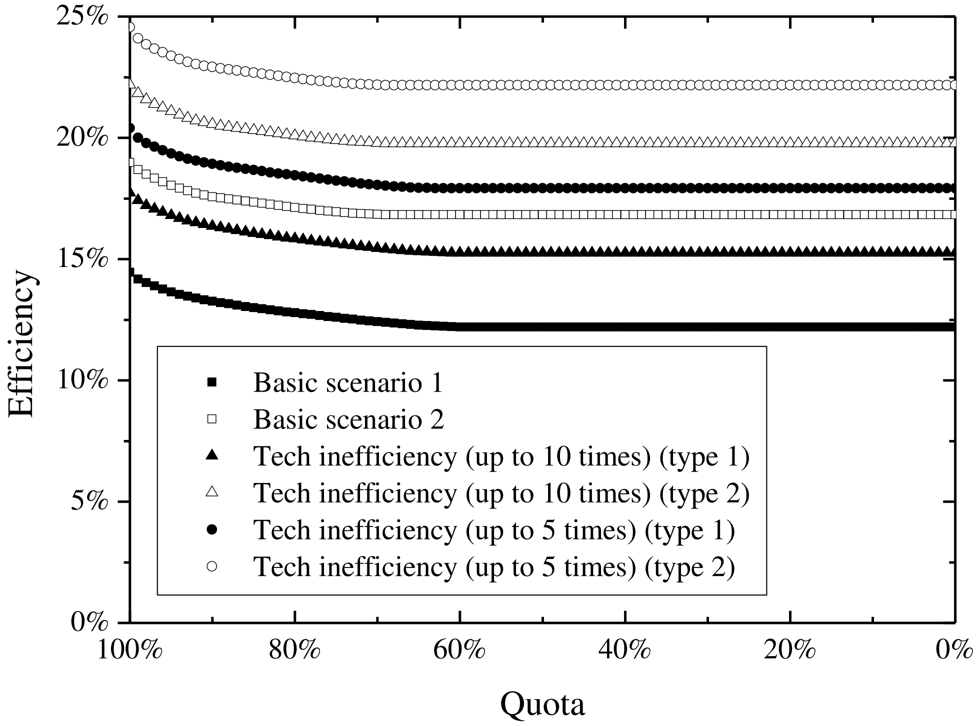

Fig.7. Efficiency Level (Three Outputs Case: TAC and other fish, other marine animals)

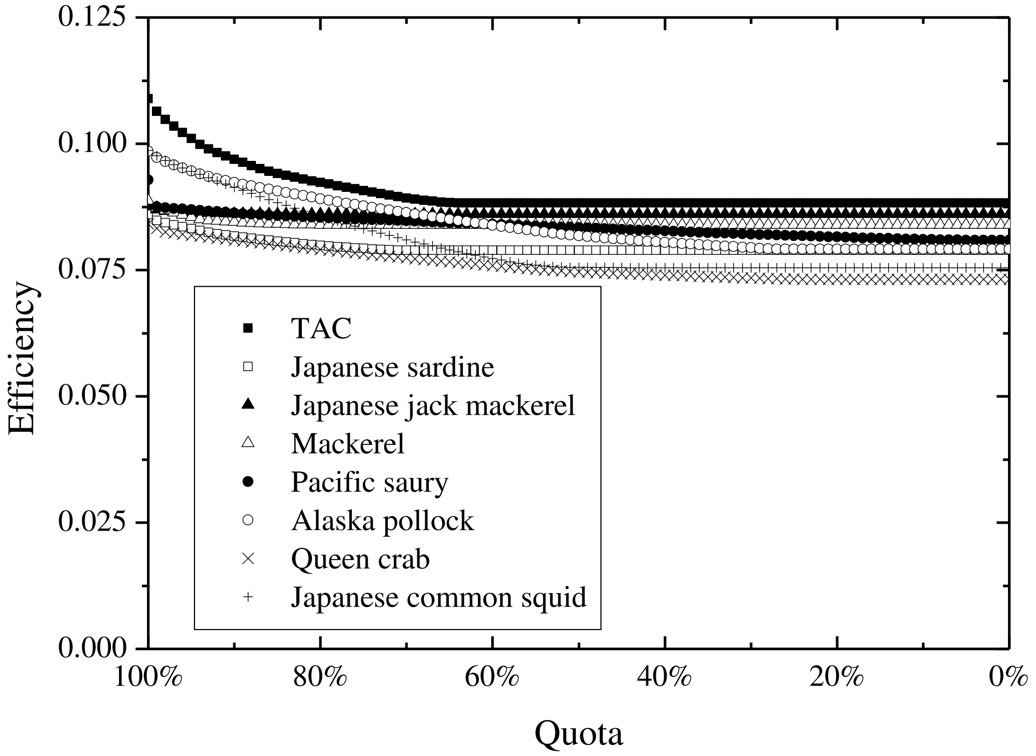

Fig.8. Efficiency Level (Two Outputs Case: Basic scenario 1)

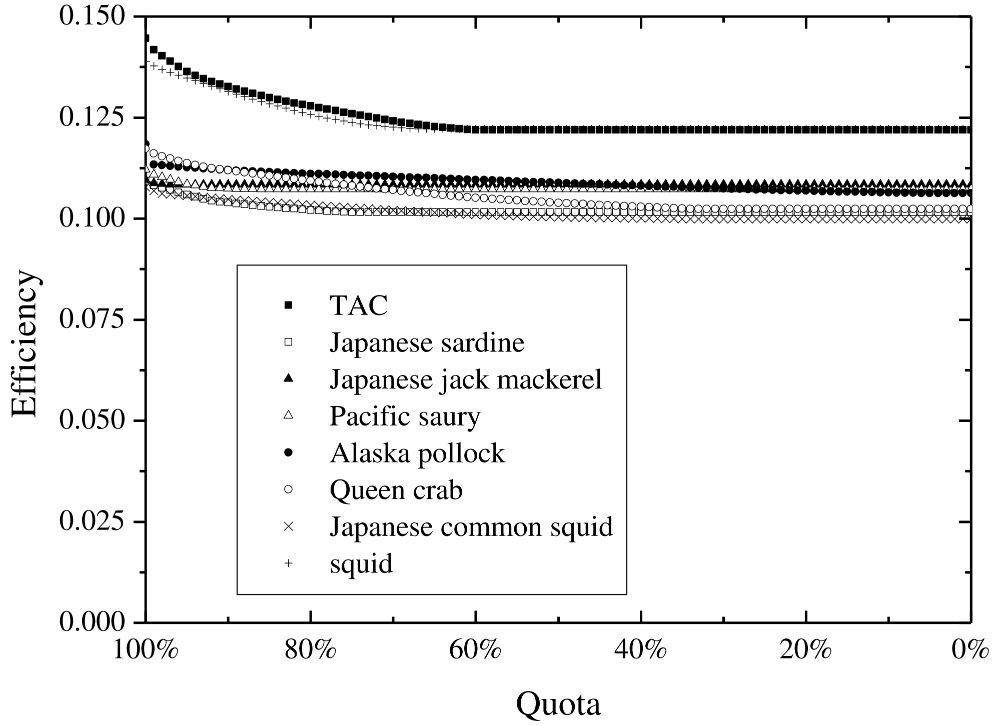

Fig.9. Efficiency Level (Three Outputs Case: Basic scenario 1)

Table 1. Technology (marine fisheries)

Fishery type 1	Large classification	Small classification (39 types of fishery): Fishery type 2
1	Trawls	(1) Distant water trawls, (2) Large trawls in East China sea, Off-shore trawl ((3) one-boat operation, (4) two-boats operation), Small trawl ((5) “Teguri” type 1, (6) other kind of “Teguri”, (7) Small sail trawl)
2	Boat seine	(8) Drag net, (9) Pulling net
3	Beach seine	(10) Beach seine
4	Surrounding nets	Large and medium surrounding net ((11) One-boat operation (skipjack and tuna on distant water), (12) One-boat operation (skipjack and tuna on off-shore water), (13) Other than skipjack and tuna, one-boat operation), (14) Two-boats operation, Purse seine ((15) One-boat operation, (16) Two-boats operation, (17) Other surrounding nets)
5	Gill nets	(18) Salmon drift gill net, (19) Billfish drift gill net, (20) Other gill nets
6	Lift nets	(21) Saury stick-held dip net, (22) Other lift nets
7	Fixed net	(23) Large set net, (24) Salmon set net, (25) Small set net
8	Other nets	(26) Other nets
9	Long lines	(27) Tuna long line on distant water, (28) Tuna long line on off-shore water, (29) Tuna long line on coastal water, (30) Other long lines
10	Anglings	(31) Skipjack pole-and-line on district water, (32) Skipjack pole-and-line on off-shore water, (33) Skipjack pole-and-line on coastal water, (34) Squid angling on distant water, (35) Squid angling on off-shore water, (36) Squid angling on coastal water, (37) Mackerel angling, (38) Trolling line fishery, (39) Other anglings

Table 2. Scenario Options

Scenario	Constraints of formulation (17) involved
Basic Scenario 1	$\alpha = 0; 0 \le Q_1 \le 1;$ fishery type 1
Basic Scenario 2	$\alpha = 0; 0 \le Q_1 \le 1;$ fishery type 2
Tolerating technical inefficiency (up to ×10)	$\alpha = 0.1; 0 \le Q_1 \le 1;$ fishery type1 or 2
Tolerating technical inefficiency (up to ×5)	$\alpha = 0.2; 0 \le Q_1 \le 1;$ fishery type1 or 2

Table 3. Estimated marine fishery income and fishery expenditures of the whole fishing industry in Japan in 2003

	Individuals		Firms	Joint management	Fisheries cooperative	Fisheries productive cooperation	Public office	Total	
# of entities	73,868		1,651	2,561	167	111	58	78,416	
Average marine fishing entities									
	Family operation	Employment operation							
Fishery income (million yen)	5.4	69.8	293.6	51.3	unknown	unknown	unknown	unknown	
Fishery expenditures	3.2	71.5	310.5	42.0					
Wage	0.4	24.6	110.3	15.3					
Vessels	0.3	1.3	9.2	0.4					
Fishing gears	0.2	2.0	8.5	1.2					
Oil	0.5	9.6	42.0	5.1					
Sale fee	0.3	3.1	11.1	2.5					
Cost depreciation	0.6	6.0	22.6	1.8					
Fishery profit	2.3	−1.8	−16.9	9.2					
Fishery income	5.4	69.8	293.6	51.3					
Total fishery income (million yen)	480,981.0							1,063,333.1	
Estimated value									
	Family operation	Employment operation							
Estimated # of entities	72,605	1,263							
Fishery income (million yen)	392,865.7	88,115.3	484,690.7	131,317.8				1,096,989.5	100.0%
Fishery expenditures	229,431.8	90,355.9	512,642.1	107,646.5				940,076.3	85.7%
Wage	29,042.0	31,121.4	182,138.3	39,134.6				281,436.4	25.7%
Vessels	22,217.1	1,597.7	15,169.4	1,132.0				40,116.2	3.7%
Fishing gears	14,956.6	2,577.8	14,028.5	3,139.8				34,702.7	3.2%
Oil	35,068.2	12,118.4	69,370.1	13,084.1				129,640.9	11.8%
Sale fee	22,362.3	3,964.5	18,382.2	6,305.2				51,014.3	4.7%
Cost depreciation	42,546.5	7,610.8	37,306.0	4,604.7				92,068.0	8.4%
Fishery profit	163,433.9	−2,240.6	−27,949.8	23,671.3				156,914.9	14.3%

Notes: The data comes from *the 11th Fishery Census of Japan of 2003* and *Statistical Survey Report on Fishery Management of 2003*.

Table 4. Simple average Capacity Utilization among aggregated entities per fishery type

						Basic scenario 1				Basic scenario 2			
						Production value		Estimated Production Quantities		Production value		Estimated Production Quantities	
						(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Fishery type1	Fishery type2	Pelagic fishery	Offshore fishery	Coastal fishery	obs	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}
Total		✓	✓	✓		0.251	0.628	0.230	0.641	0.355	0.660	0.355	0.660
1		✓	✓	✓	898	0.272	0.689	0.238	0.676	0.456	0.731	0.456	0.731
	1	✓			4	0.557	0.629	1.000	1.000	0.579	0.620	1.000	1.000
	2	✓			4	0.254	0.848	0.793	0.793	0.274	0.683	0.793	0.793
	3		✓		66	0.535	0.742	0.707	0.788	0.587	0.766	0.707	0.788
	4		✓		12	0.859	0.933	0.949	0.951	0.508	0.822	0.949	0.951
	5		✓	✓	189	0.354	0.722	0.448	0.709	0.146	0.712	0.448	0.709
	6		✓	✓	614	0.206	0.667	0.413	0.724	0.223	0.654	0.413	0.724
	7		✓	✓	9	0.225	0.750	0.700	0.797	0.141	0.628	0.700	0.797
2			✓	✓	488	0.368	0.694	0.344	0.700	0.441	0.706	0.441	0.706
	8		✓	✓	326	0.348	0.651	0.400	0.681	0.367	0.657	0.400	0.681
	9		✓	✓	162	0.408	0.780	0.522	0.756	0.296	0.786	0.522	0.756
3	10			✓	24	0.763	0.830	0.763	0.830	0.763	0.830	0.763	0.830
4		✓	✓	✓	204	0.387	0.762	0.344	0.750	0.610	0.778	0.610	0.778
	11	✓			8	0.888	0.923	1.000	1.000	0.688	0.874	1.000	1.000
	12		✓		3	0.893	0.982	0.934	1.000	0.397	0.929	0.934	1.000
	13		✓		25	0.657	0.820	0.737	0.802	0.691	0.836	0.737	0.802
	14		✓		4	0.603	0.916	1.000	1.000	0.906	0.942	1.000	1.000
	15		✓	✓	98	0.307	0.779	0.526	0.752	0.236	0.761	0.526	0.752
	16		✓	✓	29	0.331	0.721	0.603	0.781	0.333	0.684	0.603	0.781
	17		✓	✓	37	0.290	0.640	0.603	0.739	0.262	0.650	0.603	0.739
5			✓	✓	1546	0.236	0.649	0.234	0.654	0.245	0.623	0.245	0.623
	18		✓	✓	10	0.365	0.637	0.532	0.601	0.248	0.689	0.532	0.601
	19		✓	✓	11	0.614	0.796	0.993	0.993	0.647	0.840	0.993	0.993
	20		✓	✓	1525	0.233	0.648	0.237	0.620	0.231	0.653	0.237	0.620
6			✓	✓	176	0.542	0.744	0.511	0.736	0.593	0.766	0.593	0.766
	21		✓	✓	50	0.672	0.814	0.693	0.833	0.682	0.822	0.693	0.833
	22		✓	✓	126	0.490	0.717	0.553	0.740	0.443	0.702	0.553	0.740
7				✓	1145	0.226	0.602	0.221	0.600	0.339	0.655	0.339	0.655
	23			✓	300	0.331	0.750	0.380	0.692	0.328	0.749	0.380	0.692
	24			✓	82	0.254	0.506	0.295	0.504	0.256	0.506	0.295	0.504
	25			✓	763	0.182	0.554	0.328	0.657	0.175	0.552	0.328	0.657
8	26		✓	✓	96	0.433	0.636	0.433	0.636	0.433	0.636	0.433	0.636

9		✓	✓	✓	707	0.374	0.730	0.364	0.741	0.473	0.722	0.473	0.722
	27	✓			59	0.474	0.821	0.684	0.801	0.401	0.821	0.684	0.801
	28		✓		68	0.644	0.883	0.733	0.892	0.684	0.890	0.733	0.892
	29		✓	✓	60	0.420	0.716	0.602	0.716	0.394	0.746	0.602	0.716
	30		✓	✓	520	0.322	0.701	0.399	0.692	0.315	0.712	0.399	0.692
10		✓	✓	✓	2199	0.150	0.529	0.113	0.572	0.292	0.611	0.292	0.611
	31	✓			18	0.715	0.894	0.799	0.802	0.749	0.885	0.799	0.802
	32		✓		17	0.701	0.885	0.853	0.876	0.664	0.869	0.853	0.876
	33		✓	✓	36	0.227	0.500	0.625	0.827	0.210	0.565	0.625	0.827
	34	✓			7	0.624	0.811	0.995	1.000	0.674	0.785	0.995	1.000
	35		✓		27	0.346	0.589	0.723	0.812	0.379	0.626	0.723	0.812
	36		✓	✓	493	0.208	0.484	0.270	0.486	0.188	0.521	0.270	0.486
	37		✓	✓	16	0.085	0.435	0.726	0.769	0.085	0.477	0.726	0.769
	38		✓	✓	310	0.118	0.406	0.287	0.492	0.106	0.450	0.287	0.492
	39		✓	✓	1275	0.111	0.566	0.259	0.667	0.059	0.613	0.259	0.667

Table 5. Computed Fishery Expenditures of Each Scenario

	Costs			Total
	Vessels & Fishing gears (θ)	Oil $\left(\frac{\sum w_j^{*2} \cdot x_{j,f,2}^{*} \cdot x_{j,v,1}^{*}}{X_{f,1} \cdot X_{v,1}}\right)$	Wages $\left(\frac{\sum w_j^{*2} \cdot x_{j,v,1}^{*} \cdot x_{j,v,2}^{*}}{X_{v,1} \cdot X_{v,2}}\right)$	
Current situation (unit: billions of yen)	63.5	110.2	239.2	412.9
1 output; Production value				
Basic scenario 1 (10 fishing types)	10.21%	11.99%	35.26%	25.20%
Technical inefficiency (up to ×10)	15.57%	18.72%	45.43%	33.71%
Technical inefficiency (up to ×5)	20.96%	25.15%	53.65%	41.02%
Basic scenario 2 (39 fishing types)	16.93%	19.31%	44.14%	33.33%
Technical inefficiency (up to ×10)	23.93%	25.16%	50.82%	39.83%
Technical inefficiency (up to ×5)	29.21%	32.96%	61.49%	48.90%
1 output; Production quantity				
Basic scenario 1 (10 fishing types)	7.21%	8.30%	28.78%	20.00%
Technical inefficiency (up to ×10)	9.62%	11.62%	27.51%	20.52%
Technical inefficiency (up to ×5)	12.55%	10.79%	31.81%	23.24%
Basic scenario 2 (39 fishing types)	12.99%	14.64%	35.64%	26.55%
Technical inefficiency (up to ×10)	17.00%	19.20%	40.87%	31.41%
Technical inefficiency (up to ×5)	19.74%	22.05%	44.24%	34.55%
2 outputs; TAC and other species				
Basic scenario 1 (10 fishing types)	10.90%	12.73%	36.54%	26.24%
Technical inefficiency (up to ×10)	13.50%	16.20%	39.98%	29.56%
Technical inefficiency (up to ×5)	16.84%	20.19%	44.78%	33.92%
Basic scenario 2 (39 fishing types)	16.89%	19.77%	42.99%	32.78%
Technical inefficiency (up to ×10)	20.47%	23.51%	47.88%	37.16%
Technical inefficiency (up to ×5)	23.07%	25.98%	51.10%	40.08%
2 outputs; Each species and other species				
Japanese sardine	8.60%	9.60%	26.24%	19.09%
Japanese jack mackerel	8.77%	10.17%	30.58%	21.78%
Mackerel	8.87%	10.26%	28.89%	20.84%
Pacific saury	9.29%	11.13%	37.32%	26.02%
Alaska Pollock	9.85%	11.24%	35.95%	25.34%
Queen crab	8.42%	9.48%	30.45%	21.46%
Japanese Common Squid	9.87%	11.56%	29.49%	21.69%
3 outputs; TAC, other fish and other marine animals				
Basic scenario 1 (10 fishing types)	14.46%	16.75%	44.17%	32.28%
Technical inefficiency (up to ×10)	17.72%	20.62%	46.94%	35.42%
Technical inefficiency (up to ×5)	20.39%	23.75%	49.77%	38.30%
Basic scenario 2 (39 fishing types)	18.99%	22.05%	46.28%	35.61%
Technical inefficiency (up to ×10)	22.19%	25.37%	51.08%	39.77%
Technical inefficiency (up to ×5)	24.56%	27.60%	53.59%	42.18%
3 outputs; Each species, other fish and other marine animals				
Japanese sardine	10.94%	12.29%	31.36%	23.13%
Japanese jack mackerel	10.96%	12.58%	35.48%	25.59%
Mackerel	11.21%	12.75%	33.78%	24.69%
Pacific saury	11.84%	13.90%	40.44%	28.96%
Alaska Pollock	11.72%	13.25%	38.13%	27.43%
Queen crab	10.78%	12.11%	32.25%	23.57%
Japanese Common Squid	13.88%	15.82%	40.58%	29.86%

Appendix Policy Brief (only online version)

In general, the existence of overcapitalization is often attributed to the lack of property rights for fisheries (Pascoe et al., 2004). Various types of property rights with different characteristics have been used to address common-pool resource externalities and include the community management of fisheries (Grafton et al., 2000). Japan's coastal fisheries, in particular, appear to satisfy the conditions for enduring community rights (Asche et al., 2008). This is because most coastal fisheries in Japan illustrate how communities can effectively manage resources in a sustainable way and provide substantial benefits to fishers through a mix of community and private rights (Ruddle, 1989; Yamamoto, 1995).

Meanwhile, the transferability of individual quotas provides incentives for efficient harvesters to acquire quotas from less efficient harvesters, leading to a reduction in harvesting capacity (Asche et al. 2008). This will improve overall harvesting efficiency in the fisheries and generate rent. In principle, a well-designed individual transferable quota (ITQ) system – one of the catch share systems – will allow resource rents to be generated through a reduction in excess capacity arising from quota trading, although there is also evidence that this is a long-term process that may take substantial time (Grafton et al., 2000; Asche et al., 2008).

Due to a lack of property rights, the close-knit communities of fisheries in Japan will be mostly unwilling to admit that it is necessary to improve management efficiency via productive fishermen or fishing entities. Profitable communities would be reluctant to receive productive fishermen from outside because community members would not want to decrease their present profit and because young people living in the communities would desire to take any open positions. On the other hand, unprofitable fishery communities would also not want to include outside fishermen or restructure because already low profits might be further subdivided. Even if unprofitable communities seem to recruit outside fishermen, there could only be jobs available that do not allow for high productivity, jobs that even the young people living there would not want to do in most cases.

However, all ITQ programs share the problem of initial quota allocations to fishers (Grafton et al., 1996). In many countries, the implementation of the individual property rights system has been difficult because of political, ideological and regulatory issues. For example, there are strong obstacles to the implementation of incentive-based policies such as ITQs in Japan because no previous studies have estimated the potential of alternative policies and there is concern about opening the community up to the possibility of an uncertain outcome (Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2008).

In the theoretical and empirical economic literature on fisheries, the recommended policy prescription for fisheries management is the catch shares system. Catch shares grant each fisherman the right to harvest a given percentage of the total allowable catch. Each fisherman has an incentive to manage his percentage well because the value of these shares increases with the productivity of the fishery product. For example, Costello et al. (2008) show that the fisheries management strategy of catch shares can reverse a collapse in fisheries. They find that the proportion of fisheries managed by ITQs that had gone into bankruptcy by 2003 was half that of non-ITQ fisheries. On this basis, it would seem that the alternative policy is better for both fish and fishermen.

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Appendix Tables (only online version)

Table A1. Descriptive Statistics

	Total	Sample Mean	Sample Variance	Median	Minimum	Maximum	Standard Deviation
Production value (Millions of Yen)	932176.11	124.57	368548.18	20.80	0.01	25894.30	607.08
# of Management entities	74722	9.99	245.96	5.00	1.00	358.00	15.68
Fishing days (average)	-	164.06	4179.12	158.00	1.00	365.00	64.65
# of Fishermen	169800	22.69	2213.11	11.00	1.00	1894.05	47.04
Powered vessels							
Number	77395	10.47	256.93	5.00	1.00	365.00	16.03
Tonnage (GRT)	722019.38	97.94	347865.53	23.95	0.10	30511.00	589.80
Horsepower (kilowatt)	5037164.95	675.45	2055318.90	255.99	2.20	39599.50	1433.64
Production quantity (Thousands of metric tons) – Total	4018.17	0.55	8569.14	0.05	0.00	110.50	2.93
Japanese sardine	48.59	0.01	10.58	0.00	0.00	3.96	0.10
Japanese jack mackerel	217.40	0.03	126.11	0.00	0.00	12.85	0.36
Mackerel	296.02	0.04	287.34	0.00	0.00	20.10	0.54
Pacific saury	264.66	0.04	582.53	0.00	0.00	40.58	0.76
Alaska Pollock	212.60	0.03	162.27	0.00	0.00	24.63	0.40
Queen crab	5.15	0.00	0.15	0.00	0.00	0.74	0.01
Japanese Common Squid	250.93	0.03	113.69	0.00	0.00	20.42	0.34
TAC (a total of above 7 species)	1295.36	0.17	1992.74	0.01	0.00	40.58	1.41

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2005a, "*the 11th Fishery Census of Japan of 2003*". Ministry of Agriculture, Forestry and Fisheries of Japan, 2003, "*Annual Statistics of Fishery and Fish Culture 2003*"

Table A2. Catch value and number of DMU classified by the fishery type and sea area

		Fishery type										Total
Area		1	2	3	4	5	6	7	8	9	10	
Hokkaido Pacific Ocean, North	# of DMUs	40	-	-	1	66	13	91	-	38	45	294
	# of entities	504	-	-	1	1199	102	637	-	259	234	2936
	Production Value	23.8	-	-	1.5	21.1	12.1	26.5	-	6.5	7.7	99.2
Pacific Ocean, North	# of DMUs	67	49	-	11	119	33	105	-	58	111	553
	# of entities	494	429	-	29	1500	80	447	-	269	1003	4251
	Production Value	20.4	5.8	-	21.3	5.9	6.3	17.9	-	58.5	19.2	155.2
Pacific Ocean, Middle	# of DMUs	91	67	8	35	214	17	138	26	72	325	993
	# of entities	1312	607	31	67	2806	43	458	184	382	3707	9597
	Production Value	14.6	17.6	0.1	44.0	9.6	3.0	11.2	0.7	37.4	27.4	165.5
Pacific Ocean, South	# of DMUs	52	48	1	52	130	18	105	16	139	310	871
	# of entities	383	205	1	209	1398	120	322	79	850	4977	8544
	Production Value	4.5	3.6	0.2	14.6	2.6	0.5	5.6	0.2	35.7	29.1	96.6
Hokkaido Japan Sea, North	# of DMUs	32	-	-	1	49	11	73	2	23	45	236
	# of entities	204	-	-	2	700	44	561	2	172	395	2080
	Production Value	42.6	-	-	0.0	7.9	0.3	11.2	0.1	7.6	6.8	76.6
Japan Sea, North	# of DMUs	62	17	3	1	121	7	96	-	39	115	461
	# of entities	329	37	4	1	1850	19	697	-	127	890	3954
	Production Value	5.9	0.3	0.0	1.9	4.5	1.0	11.4	-	5.2	4.7	34.8
Japan Sea, West	# of DMUs	92	32	5	17	110	6	124	2	37	225	650
	# of entities	640	88	11	31	1670	20	462	18	256	2770	5966
	Production Value	26.7	0.3	0.1	14.7	4.6	0.2	12.3	0.1	1.1	13.3	73.5
East China Sea	# of DMUs	135	115	4	69	384	57	271	38	199	716	1988
	# of entities	1340	669	14	178	4294	265	812	103	1468	11686	20829
	Production Value	9.9	7.5	0.1	41.4	13.3	2.6	9.8	0.6	26.7	33.7	145.7
Seto Inland Sea	# of DMUs	327	160	3	17	353	14	142	12	102	307	1437
	# of entities	5245	726	6	29	4021	57	612	46	470	5358	16570
	Production Value	32.3	23.7	0.0	4.3	10.6	0.7	2.8	0.3	2.3	8.2	85.1
All areas	# of DMUs	898	488	24	204	1546	176	1145	96	707	2199	7483
	# of entities	10451	2761	67	547	19438	750	5008	432	4253	31020	74727
	Production Value	180.8	58.7	0.4	143.7	80.0	26.7	108.6	2.0	180.9	150.2	932.2

*Production value (unit: Billions of Yen)
Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2005a, “*the 11th Fishery Census of Japan of 2003”*

Table A3. Catch value and quantity classified by fishery type

	Sample Data	Statistical Data										
Fishery type 2	Production value (Billions of Yen)	Production value	Total production quantity									
				Fish	Other marine animal	Japanese sardine	Japanese jack mackerel	Mackerel	Pacific saury	Alaska Pollock	Queen crab	Japanese Common Squid
1	7.5	16.8	140.3	59.1	81.1	-	-	-	-	5.9	-	-
2	1.9	2.5	8.5	6.8	1.7	-	0.4	-	-	-	-	0.0
3	50.8	46.7	364.2	314.1	50.2	0.0	0.2	0.0	-	134.8	4.0	32.3
4	11.7	9.9	26.5	20.9	5.6	-	0.5	-	-	3.5	-	3.1
5	29.1	25.3	45.8	34.6	11.2	0.0	0.9	0.1	0.0	1.1	0.9	0.5
6	79.6	88.4	451.3	41.5	409.9	0.0	1.1	0.0	-	0.2	0.0	0.2
7	0.1	0.2	0.2	0.1	0.1	-	-	-	-	-	-	-
8	51.0	46.8	223.1	170.7	52.4	0.4	0.3	0.1	-	-	-	0.0
9	7.7	8.3	20.2	19.4	0.7	0.0	0.2	0.0	-	0.0	0.0	0.0
10	0.4	0.5	1.3	1.3	0.0	0.1	0.3	0.0	-	-	-	0.0
11	37.0	25.6	157.8	157.8	0.0	-	-	-	-	-	-	-
12	7.0	15.7	64.5	64.5	0.0	-	-	-	-	-	-	-
13	52.7	54.8	611.1	596.8	14.3	36.2	117.6	183.9	0.0	-	-	14.3
14	3.1	2.2	56.6	56.4	0.1	1.8	0.0	1.1	-	-	-	0.1
15	32.7	42.6	317.5	316.3	1.3	6.0	73.4	80.7	0.2	-	-	0.7
16	8.3	8.7	83.5	83.4	0.1	2.2	8.3	4.6	0.0	-	-	0.0
17	2.8	3.1	23.6	23.5	0.0	0.7	0.4	0.7	-	-	-	0.0
18	2.5	6.5	9.4	9.4	0.0	-	-	-	-	-	-	-
19	2.3	2.3	6.4	6.4	0.0	-	-	-	-	-	-	-
20	75.1	71.9	183.8	167.5	16.3	0.1	1.3	0.6	3.1	45.5	0.2	5.8
21	21.1	16.5	255.5	255.5	0.0	0.0	-	0.0	255.5	-	-	-
22	5.6	9.3	48.5	46.5	2.0	0.6	2.0	13.0	0.1	-	-	0.1
23	50.7	47.5	236.5	196.8	39.8	2.6	22.2	31.6	5.5	7.6	-	33.4

24	29.3	33.0	215.6	213.9	1.7	0.0	0.0	0.4	0.0	0.3	-	1.6
25	28.7	33.9	152.8	137.1	15.6	1.2	8.2	2.2	0.3	7.0	-	7.7
26	2.0	2.4	11.8	10.9	0.8	0.2	0.0	5.4	-	-	-	-
27	127.0	89.8	136.1	136.1	0.0	-	-	-	-	-	-	-
28	23.8	27.0	56.9	56.9	0.0	-	-	-	-	-	-	-
29	5.1	5.6	9.8	9.8	0.0	-	-	-	-	-	-	-
30	25.0	20.8	44.0	35.2	8.8	-	0.1	0.0	-	13.7	-	0.0
31	21.0	20.3	97.5	97.5	0.0	-	-	-	-	-	-	-
32	14.0	14.9	57.9	57.9	0.0	-	-	-	-	-	-	-
33	3.2	4.2	10.9	10.9	0.0	-	-	-	-	-	-	-
34	8.2	10.4	60.4	0.0	60.4	-	-	-	-	-	-	1.3
35	13.4	13.5	70.8	0.0	70.8	-	-	-	-	-	-	56.7
36	40.4	39.3	114.8	0.0	114.8	-	-	-	-	-	-	96.2
37	0.8	1.0	2.9	2.9	0.0	-	0.0	2.5	-	-	-	-
38	10.3	13.8	30.6	30.5	0.1	-	0.0	0.1	-	-	-	-
39	38.9	33.4	48.1	46.1	2.0	0.0	4.3	2.2	0.0	0.1	-	0.0

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2005b, “*Annual Statistics of Fishery and Fish Culture 2003”*

Table A4. Production classified by area

	Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea
Production value (Billions of Yen)	99.2	155.2	165.5	96.6	76.6	34.8	73.5	145.7	85.1
Production quantity (Thousands of metric tons)									
Total	559.7	629.7	680.4	349.2	370.5	118.6	398.0	659.9	314.8
Japanese sardine	0.2	7.9	6.3	6.1	0.2	0.5	7.7	18.3	1.3
Japanese jack mackerel	2.1	29.4	24.7	29.9	1.6	4.6	35.1	84.2	5.8
Mackerel	2.1	43.7	32.2	41.5	0.9	5.0	49.0	116.6	5.0
Pacific saury	147.5	74.9	23.1	0.8	3.0	12.4	1.3	1.2	0.5
Alaska Pollock	46.8	34.8	12.9	4.5	37.2	7.8	47.8	14.7	8.7
Queen crab	1.0	0.8	0.1	0.0	0.9	0.2	1.5	0.1	0.4
Japanese Common Squid	25.7	65.2	10.8	6.1	19.9	15.5	56.0	49.8	1.9
TAC (a total of above 7 species)	225.6	256.7	110.2	89.0	63.7	46.1	198.4	284.8	23.6

Source: Ministry of Agriculture, Forestry and Fisheries of Japan, 2005b, "*Annual Statistics of Fishery and Fish Culture 2003*"

Table A5. Aggregated Vessel Excess Capacity (%) (1, 2 and 3 outputs; Fishery type 1 and 2)

	Areas									Total
	Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea	
1 output										
Production value; Fishery type 1	187.4%	96.4%	197.5%	169.9%	244.5%	98.9%	148.4%	478.4%	1419.0%	328.43%
Production value; Fishery type 2	133.6%	58.1%	151.0%	60.7%	151.9%	71.7%	95.0%	195.3%	387.3%	145.50%
Production quantity; Fishery type 1	170.3%	104.9%	185.6%	194.2%	270.0%	125.9%	161.1%	412.5%	658.5%	248.49%
Production quantity; Fishery type 2	111.3%	53.2%	108.2%	53.9%	157.7%	66.5%	80.1%	145.9%	241.8%	112.42%
2 outputs; Fishery type 1										
Japanese sardine	140.5%	32.4%	135.3%	73.7%	139.9%	109.2%	121.5%	121.1%	102.2%	102.11%
Japanese jack mackerel	152.9%	64.2%	197.6%	104.9%	158.0%	99.7%	152.0%	170.5%	257.7%	147.78%
Mackerel	114.1%	40.1%	178.1%	115.9%	197.7%	66.5%	144.1%	149.3%	105.6%	128.54%
Pacific saury	13.2%	79.4%	61.7%	95.8%	24.1%	6.5%	201.7%	317.9%	261.4%	38.99%
Alaska Pollock	62.0%	75.7%	689.0%	111.7%	51.7%	104.3%	55.7%	263.3%	342.3%	126.38%
Queen crab	29.4%	69.2%	348.7%	104.0%	33.1%	114.4%	65.4%	153.6%	1530.7%	187.84%
Japanese Common Squid	59.2%	56.8%	315.1%	117.4%	72.9%	113.7%	115.3%	672.0%	414.9%	212.27%
TAC (a total of above 7 species)	31.5%	62.2%	238.7%	117.1%	62.7%	73.7%	113.5%	254.6%	279.1%	130.02%
Other marine animals (non-TAC species)	191.4%	85.9%	136.9%	160.8%	196.0%	97.9%	144.2%	254.6%	626.2%	211.91%
2 outputs; Fishery type 2										
TAC (a total of above 7 species)	26.1%	53.4%	174.1%	51.9%	53.2%	57.6%	78.5%	183.3%	254.8%	94.93%
Other marine animals (non-TAC species)	168.7%	53.0%	95.4%	54.6%	179.4%	72.1%	81.7%	117.4%	240.7%	120.56%
3 outputs; Fishery type 1										
Japanese sardine	137.5%	31.0%	133.5%	71.8%	139.0%	102.4%	120.1%	118.6%	94.5%	99.97%
Japanese jack mackerel	151.5%	61.5%	195.4%	104.1%	155.9%	94.2%	150.9%	168.7%	219.0%	144.98%
Mackerel	84.9%	39.6%	176.0%	111.6%	111.9%	65.2%	141.7%	144.8%	90.6%	124.74%
Pacific saury	13.1%	79.4%	61.6%	95.3%	19.8%	6.5%	201.0%	314.8%	260.9%	38.86%
Alaska Pollock	60.8%	74.0%	688.4%	110.5%	50.0%	104.1%	54.9%	262.7%	338.5%	125.10%
Queen crab	29.3%	69.1%	348.3%	103.9%	33.1%	113.9%	64.9%	153.5%	1529.3%	187.52%
Japanese Common Squid	55.7%	51.9%	300.2%	103.4%	68.4%	107.8%	111.2%	658.7%	390.5%	205.19%
TAC (a total of above 7 species)	29.7%	59.8%	194.0%	73.5%	57.2%	71.0%	88.5%	198.1%	266.1%	105.65%

Other fishes (non-TAC species)	122.5%	77.8%	125.7%	142.8%	170.3%	85.5%	104.9%	169.5%	306.7%	141.45%
Other marine animals (non-TAC species)	363.7%	72.1%	100.3%	119.5%	198.6%	104.6%	100.5%	312.1%	350.5%	222.88%
3 outputs; Fishery type 2										
TAC (a total of above 7 species)	26.1%	52.8%	174.0%	51.8%	53.2%	57.6%	78.4%	182.3%	254.8%	94.57%
Other fishes (non-TAC species)	110.9%	52.4%	95.6%	52.8%	162.9%	72.2%	82.2%	100.9%	285.8%	104.67%
Other marine animals (non-TAC species)	351.4%	56.1%	94.2%	83.8%	192.6%	71.2%	77.4%	276.5%	175.9%	178.03%

Table A6. Industry Model Scenarios: Efficiency measure and activity vectors (total and per area)

		All areas	Hokkaido Pacific Ocean, North	Pacific Ocean, North	Pacific Ocean, Middle	Pacific Ocean, South	Hokkaido Japan Sea, North	Japan Sea, North	Japan Sea, West	East China Sea	Seto Inland Sea
Actual	# of DMUs (# of entities)	7483 (74727)	294 (2936)	553 (4251)	993 (9597)	871 (8544)	236 (2080)	461 (3954)	650 (5966)	1988 (20829)	1437 (18764)
1 output; Production value	θ	# of DMUs (Mean w^*_{ja} (>0))									
Basic scenario 1 (10 fishing types)	0.102	1741 (0.997)	95	260	289	413	22	219	149	268	26
Technical inefficiency (up to ×10)	0.156	2110 (0.998)	113	282	296	401	34	220	188	491	85
Technical inefficiency (up to ×5)	0.210	2562 (0.0.998)	139	345	445	390	30	230	210	583	190
Basic scenario 2 (39 fishing types)	0.169	2429 (0.998)	96	365	300	586	20	277	270	487	28
Technical inefficiency (up to ×10)	0.239	3015 (0.998)	130	370	453	534	24	270	254	799	181
Technical inefficiency (up to ×5)	0.292	3092 (0.999)	135	367	475	540	27	266	224	787	271
1 output; Production quantity											
Basic scenario 1 (10 fishing types)	0.072	1289 (0.997)	95	193	224	160	22	122	98	302	73
Technical inefficiency (up to ×10)	0.096	1167 (0.995)	101	209	167	169	34	121	83	163	120
Technical inefficiency (up to ×5)	0.125	1304 (0.997)	102	250	160	173	26	123	100	185	185
Basic scenario 2 (39 fishing types)	0.130	1755 (0.997)	92	250	316	363	19	164	130	314	107

Technical inefficiency (up to ×10)	0.170	1979 (0.997)	98	252	327	333	21	174	130	388	256
Technical inefficiency (up to ×5)	0.197	2102 (0.998)	95	263	364	302	24	165	120	376	393
2 outputs; TAC and others											
Basic scenario 1 (10 fishing types)	0.109	1699 (0.997)	93	240	258	313	61	154	106	346	128
Technical inefficiency (up to ×10)	0.135	1808 (0.996)	96	257	246	281	62	145	100	268	353
Technical inefficiency (up to ×5)	0.168	1940 (0.996)	99	272	295	281	63	148	99	292	391
Basic scenario 2 (39 fishing types)	0.169	2268 (0.997)	99	314	351	378	56	164	136	667	103
Technical inefficiency (up to ×10)	0.205	2377 (0.996)	104	310	390	324	62	157	119	563	348
Technical inefficiency (up to ×5)	0.231	2471 (0.997)	108	306	375	328	60	164	119	576	435
2 outputs; each species and others											
Japanese sardine	0.086	1277 (0.996)	106	192	255	232	44	122	106	108	112
Japanese jack mackerel	0.088	1447 (0.995)	106	193	266	255	40	117	120	282	68
Mackerel	0.089	1389 (0.995)	104	186	269	267	34	123	118	197	91
Pacific saury	0.093	1739 (0.996)	91	187	258	268	67	113	122	377	256
Alaska Pollock	0.099	1827 (0.996)	106	218	220	308	20	163	119	472	201
Queen crab	0.084	1452 (0.996)	89	201	234	256	19	126	114	344	69
Japanese Common Squid	0.099	1455 (0.994)	120	218	232	199	63	133	185	210	95
3 outputs; TAC, other fish and other marine animals											
Basic scenario 1 (10 fishing types)	0.145	2282 (0.994)	96	258	354	373	54	165	261	550	171
Technical inefficiency (up to ×10)	0.177	2319 (0.994)	98	266	315	325	55	166	240	455	399
Technical inefficiency (up to ×5)	0.204	2301 (0.995)	98	274	312	309	54	163	219	438	434

Basic scenario 2 (39 fishing types)	0.190	2594 (0.996)	105	302	378	380	66	212	284	636	231
Technical inefficiency (up to ×10)	0.222	2735 (0.996)	105	290	383	324	63	217	267	579	507
Technical inefficiency (up to ×5)	0.246	2692 (0.995)	109	296	371	316	62	213	242	575	508
3 outputs; each species, other fish and other marine animals											
Japanese sardine	0.109	1627 (0.992)	102	239	356	259	59	134	215	114	149
Japanese jack mackerel	0.110	1758 (0.991)	105	230	359	279	58	134	215	259	119
Mackerel	0.112	1762 (0.994)	104	219	358	308	47	142	217	219	148
Pacific saury	0.118	1993 (0.993)	96	235	358	290	68	133	208	284	321
Alaska Pollock	0.117	2093 (0.994)	116	255	349	336	23	160	221	406	227
Queen crab	0.108	1693 (0.993)	92	238	342	254	24	141	233	242	127
Japanese Common Squid	0.139	2109 (0.994)	117	258	359	330	64	156	263	441	121

Table A7. Optimum Input Allocations for Each Scenario

	Tonnage θ	Horsepower θ	Fishing days (average) $\sum w_j^{*2} \cdot x_{j,v,1}^{*} / X_{v,1}$ $(w_j^{*} \neq 0)$	Labor $\sum w_j^{*} \cdot x_{j,v,2}^{*} / X_{v,2}$	Overall average *w*
Current situation (100%)	732906.4	5054382.0	164.1	169800	
1 output; Production value					
Basic scenario 1 (10 fishing types)	10.21%	10.21%	113.32%	35.69%	0.232
Technical inefficiency (up to ×10)	15.57%	15.57%	119.43%	41.62%	0.281
Technical inefficiency (up to ×5)	20.96%	20.96%	120.45%	48.59%	0.342
Basic scenario 2 (39 fishing types)	16.93%	16.93%	112.72%	43.81%	0.324
Technical inefficiency (up to ×10)	23.93%	23.93%	114.81%	53.83%	0.402
Technical inefficiency (up to ×5)	29.21%	29.21%	116.50%	58.45%	0.413
1 output; production quantity					
Basic scenario 1 (10 fishing types)	7.21%	7.21%	114.74%	29.03%	0.234
Technical inefficiency (up to ×10)	9.62%	9.62%	125.27%	24.59%	0.155
Technical inefficiency (up to ×5)	12.55%	12.55%	126.58%	27.91%	0.174
Basic scenario 2 (39 fishing types)	12.99%	12.99%	112.99%	35.36%	0.234
Technical inefficiency (up to ×10)	17.00%	17.00%	118.77%	38.66%	0.264
Technical inefficiency (up to ×5)	19.74%	19.74%	120.67%	41.65%	0.280
2 outputs; TAC and other species					
Basic scenario 1 (10 fishing types)	10.90%	10.90%	120.79%	34.03%	0.226
Technical inefficiency (up to ×10)	13.50%	13.50%	122.75%	35.50%	0.241
Technical inefficiency (up to ×5)	16.84%	16.84%	125.13%	39.42%	0.258
Basic scenario 2 (39 fishing types)	16.89%	16.89%	116.15%	40.67%	0.302
Technical inefficiency (up to ×10)	20.47%	20.47%	119.99%	44.49%	0.316
Technical inefficiency (up to ×5)	23.07%	23.07%	121.37%	47.53%	0.329
2 outputs; each species and other species					
Japanese sardine	8.60%	8.60%	116.60%	25.31%	0.170
Japanese jack mackerel	8.77%	8.77%	120.50%	28.51%	0.192
Mackerel	8.87%	8.87%	120.33%	26.88%	0.185
Pacific saury	9.29%	9.29%	119.63%	35.33%	0.231
Alaska Pollock	9.85%	9.85%	114.48%	34.05%	0.243
Queen crab	8.42%	8.42%	114.85%	30.57%	0.193

Japanese Common Squid	9.87%	9.87%	121.81%	26.83%	0.193
3 outputs; TAC, other fish and other marine animals					
Basic scenario 1 (10 fishing types)	14.46%	14.46%	119.21%	40.58%	0.303
Technical inefficiency (up to ×10)	17.72%	17.72%	122.18%	42.32%	0.308
Technical inefficiency (up to ×5)	20.39%	20.39%	123.67%	44.31%	0.306
Basic scenario 2 (39 fishing types)	18.99%	18.99%	117.02%	30.78%	0.345
Technical inefficiency (up to ×10)	22.19%	22.19%	120.07%	47.77%	0.364
Technical inefficiency (up to ×5)	24.56%	24.56%	121.13%	50.06%	0.358
3 outputs; each species, other fish and other marine animals					
Japanese sardine	10.94%	10.94%	115.21%	30.78%	0.216
Japanese jack mackerel	10.96%	10.96%	120.71%	32.77%	0.233
Mackerel	11.21%	11.21%	119.08%	31.68%	0.234
Pacific saury	11.84%	11.84%	122.19%	36.47%	0.264
Alaska Pollock	11.72%	11.72%	115.88%	36.04%	0.278
Queen crab	10.78%	10.78%	115.64%	30.44%	0.225
Japanese Common Squid	13.88%	13.88%	119.35%	37.92%	0.280

Table A8. Optimum Amounts of Inputs (Tonnage; per each fishery type)

		Fishing type 1									
	Overall	1	2	3	4	5	6	7	8	9	10
Current situation (Tonnage)	732906.4	106404.2	40993.8	166.7	79446.5	65629.1	17062.5	38003.0	1903.9	216612.6	166684.1
1 output; Production value											
Basic scenario 1 (10 fishing types)	10.21%	9.13%	1.64%	13.17%	14.44%	5.30%	11.21%	51.38%	0.17%	8.79%	5.38%
Technical inefficiency (up to ×10)	15.57%	16.28%	3.48%	16.87%	32.16%	6.75%	13.06%	68.02%	0.99%	11.69%	7.15%
Technical inefficiency (up to ×5)	20.96%	23.73%	13.58%	25.33%	44.65%	11.60%	14.42%	69.43%	1.55%	15.28%	10.64%
Basic scenario 2 (39 fishing types)	16.93%	17.04%	8.11%	18.85%	18.62%	12.67%	17.21%	52.17%	1.29%	16.69%	12.32%
Technical inefficiency (up to ×10)	23.93%	25.00%	20.28%	26.77%	41.40%	18.83%	16.53%	64.85%	5.00%	19.76%	14.88%
Technical inefficiency (up to ×5)	29.21%	30.22%	39.10%	25.33%	51.61%	21.02%	22.19%	66.73%	10.80%	23.40%	18.60%
1 output; Production quantity											
Basic scenario 1 (10 fishing types)	7.21%	7.27%	0.48%	0.00%	27.82%	1.44%	23.54%	43.30%	0.17%	0.00%	0.85%
Technical inefficiency (up to ×10)	9.62%	14.55%	0.95%	11.73%	35.88%	0.48%	24.30%	54.30%	0.32%	0.00%	0.60%
Technical inefficiency (up to ×5)	12.55%	16.53%	10.60%	11.73%	50.55%	0.50%	31.22%	60.10%	1.96%	0.04%	0.74%
Basic scenario 2 (39 fishing types)	12.99%	13.90%	7.19%	13.17%	49.01%	5.84%	32.79%	51.70%	2.37%	0.65%	4.77%
Technical inefficiency (up to ×10)	17.00%	16.26%	25.24%	11.73%	66.27%	6.00%	44.84%	62.82%	9.38%	0.78%	4.18%
Technical inefficiency (up to ×5)	19.74%	21.98%	35.28%	17.36%	70.72%	6.01%	58.89%	69.93%	11.44%	0.80%	4.86%
2 outputs; TAC and other species											
Basic scenario 1 (10 fishing types)	10.90%	18.76%	3.45%	13.17%	27.11%	2.27%	46.08%	49.33%	7.21%	0.03%	5.17%
Technical inefficiency (up to ×10)	13.50%	21.70%	5.59%	11.73%	38.61%	3.42%	46.68%	62.10%	9.93%	0.35%	4.87%
Technical inefficiency (up to ×5)	16.84%	27.96%	17.70%	11.73%	47.89%	5.09%	44.03%	68.58%	10.11%	0.98%	5.48%
Basic scenario 2 (39 fishing types)	16.89%	24.71%	15.02%	13.17%	50.70%	8.31%	38.66%	59.37%	3.12%	1.19%	8.26%
Technical inefficiency (up to ×10)	20.47%	28.58%	37.42%	11.73%	63.32%	9.01%	38.80%	69.21%	10.76%	1.39%	7.15%
Technical inefficiency (up to ×5)	23.07%	33.05%	50.56%	13.47%	68.62%	8.55%	39.68%	72.79%	11.01%	1.70%	8.84%
2 outputs; each species and other species											
Japanese sardine	8.60%	6.96%	0.80%	1.21%	38.48%	1.86%	22.17%	47.56%	1.33%	0.00%	0.96%
Japanese jack mackerel	8.77%	9.39%	1.83%	0.00%	30.02%	2.22%	24.29%	52.94%	0.65%	0.00%	2.36%
Mackerel	8.87%	7.53%	1.62%	13.17%	33.73%	2.23%	21.75%	52.92%	10.08%	0.00%	2.43%
Pacific saury	9.29%	9.53%	1.58%	11.73%	27.13%	5.86%	42.32%	52.15%	0.65%	0.00%	2.89%
Alaska Pollock	9.85%	23.73%	1.05%	0.84%	22.83%	5.67%	23.71%	49.36%	0.65%	0.20%	0.84%
Queen crab	8.42%	21.09%	0.68%	0.00%	20.94%	1.58%	23.59%	39.18%	0.65%	0.00%	1.42%
Japanese Common Squid	9.87%	10.08%	0.64%	9.68%	25.11%	1.74%	21.57%	49.94%	0.65%	0.00%	10.53%
3 outputs; TAC, other fish and other marine animals											
Basic scenario 1 (10 fishing types)	14.46%	28.75%	6.27%	11.73%	34.57%	3.80%	43.75%	58.85%	7.77%	0.03%	7.67%
Technical inefficiency (up to ×10)	17.72%	34.34%	13.92%	11.73%	46.38%	4.63%	44.02%	64.02%	10.24%	0.51%	8.75%
Technical inefficiency (up to ×5)	20.39%	38.92%	25.63%	11.73%	51.75%	5.39%	43.77%	68.14%	10.11%	1.11%	10.16%
Basic scenario 2 (39 fishing types)	18.99%	35.59%	14.80%	13.17%	49.33%	8.48%	35.62%	62.53%	4.91%	1.43%	10.44%

Technical inefficiency (up to ×10)	22.19%	42.45%	27.26%	11.73%	60.96%	9.32%	34.92%	68.03%	12.61%	1.47%	9.86%
Technical inefficiency (up to ×5)	24.56%	45.21%	39.75%	13.47%	64.93%	9.19%	38.82%	71.18%	12.70%	1.91%	11.93%
3 outputs; Each species, other fish and other marine animals											
Japanese sardine	10.94%	13.04%	2.42%	0.00%	33.42%	2.45%	28.80%	60.04%	1.33%	0.00%	5.63%
Japanese jack mackerel	10.96%	13.37%	2.56%	0.00%	24.86%	2.70%	41.20%	64.48%	0.91%	0.00%	7.17%
Mackerel	11.21%	13.69%	2.57%	11.73%	27.99%	2.67%	37.64%	62.60%	10.18%	0.00%	7.27%
Pacific saury	11.84%	14.72%	3.32%	9.68%	29.35%	6.89%	40.73%	63.81%	0.91%	0.00%	6.40%
Alaska Pollock	11.72%	28.48%	3.35%	9.68%	19.42%	6.21%	25.63%	59.97%	0.65%	0.21%	4.25%
Queen crab	10.78%	28.53%	2.42%	0.00%	16.22%	2.26%	28.58%	56.47%	0.65%	0.00%	4.17%
Japanese Common Squid	13.88%	24.75%	2.52%	11.73%	30.43%	3.50%	28.56%	60.37%	0.99%	0.00%	12.04%