# A Guide to the Economic Evaluation of Individual Transferable Quota Fisheries[1]

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**Abstract.** Detailed economic analyses of fisher performance are critical inputs in improving the management of fisheries. The paper provides guidelines about the economic methodologies and the data required to monitor and assess the performance of individual transferable quota fisheries. In particular, it describes the methods of evaluation that could be applied to examine profitability, competitiveness, efficiency, equity, productivity, output and input interactions, capacity and sustainability of such fisheries.

## I. Introduction

Individual transferable quotas (ITQs) represent a property-rights approach to addressing the externalities inherent in the exploitation of common-pool resources. Since their first use in commercial fisheries in the 1970s, ITQs have been implemented in many different countries and environments including the US, Canada, Australia, Iceland, New Zealand and the Netherlands. In recent years, different authors have provided assessments of ITQs from various perspectives[1] and several workshops and conferences have been influential in showing the advantages and potential weaknesses associated with ITQs[2]. These studies, and the lessons learnt by fishery managers when implementing ITQs, have proved useful in improving management practices. Despite these assessments, many gaps exist in terms of our understanding of the economic effects of ITQs. For example, although the often stated goal of introducing ITQs is to improve economic efficiency, very few studies exist which test for changes in efficiency following the introduction of rights-based fisheries management.

To assist researchers and managers improve the management of ITQs, this paper provides guidelines about the economic methodologies and the data required to monitor and assess the performance of fisheries, and to identify and quantify the economic benefits that can be directly attributed to the adoption of an ITQ management program. Section II provides a guide to some of the approaches to measure the on-going economic performance of fishers, section III discusses the data requirements for economic performance measures and section IV concludes.

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## II. Economic Methodologies for Monitoring Fisheries

Fishery managers are likely to be concerned about a number of economic measures including profitability, competitiveness, management quality and costs, efficiency, equity, productivity, output and input interactions, capacity and sustainability. Switching from a command and control (CAC) management program to a property rights-based program such as ITQs can impact many if not all of these measures.

Understanding and quantifying how management reform affects economic measures of performance provides important feedback for managers and resource users that can be used to assess the performance of the new management program and, if necessary, provide guidance for program design modifications. A review of some of the potential methods, and their data requirements, that could be employed to monitor economic performance in ITQ fisheries is provided below.

### *A. Profitability*

A central question of fishery managers, and often a principal reason for introducing ITQs, is to increase the net returns of fishers. Net returns may increase due to a number of factors including, rises in output prices due to increased quality of fish, or change in product form, reductions in operating costs per unit of harvest due to reductions in congestion externalities, the relaxation of input restrictions, and quota transfers that enable low cost fishers to expand their operations and take advantage of economies of scale and scope, and adjustments, over time, to optimal levels of the fixed factors used by fishers.

Several methods exist to estimate profitability of fishers. The preferred approach is to collect reliable costs and earnings data from the population, or a random sample of the population, and measure directly changes in net returns over time, accounting for the resource rent redistribution in the fishery. Such data can also be used to estimate profit and cost functions to derive measures of substitutability between inputs and between outputs and capacity utilization. In addition, mathematical programming approaches may also be used to assess resource rents in ITQ fisheries that can be used to examine the potential impacts of introducing quota programs[3].

Where reliable costs and earnings data are not available, quota price data (lease and sale prices) may be used to provide a measure of expected net returns in an ITQ fishery that exceed the normal return to the factors used to produce fish. Deriving measures of profitability from lease and sale prices of quota is, however, problematic as prices can exhibit considerable variation across time, and across trades for a given point in time[4]. Further, various factors including uncertainty, imperfect information, limitations on transferability divisibility and duration of the property and market power may distort prices such that they do not necessarily reflect the marginal value of additional unit of harvest from the resource. Finally, ITQ rental prices alone do not reflect *changes* in economic profitability that are attributable to management reform. In addition, comprehensive analysis of changes in profitability must consider the role of management operating rules on the redistribution of resource rents, as well as changes in the returns to individual fisher capital and labor endowments.

In the absence of reliable costs and earnings data, other data may also be used to assess changes in profitability. For example, if data are available on aggregate landings, consumption and output prices, it may be possible to estimate changes in prices due to the increased length of the fishing season as a result of introducing ITQs[5]. Further, log-book data may provide information on the number of fishing days and which is likely to be inversely related to congestion externalities in the fishery. Similarly, data on the number of crew employed and the number of vessels in the fishery may also provide crude measures of the level of variable and fixed inputs applied in a fishery.

### *B. Competitiveness*

An important concern for fishers is that if their competitors and fish processors achieve a degree of market power, it may reduce the price they receive for their fish or the quota they may wish to sell[6]. This issue is of interest to fishery managers because market power may distort efficiency, benefit one group of fishers at the expense of others and, if the market power is exercised in a collusory manner, may be illegal. To help address the concerns of fishers, many ITQ programs specify limits on the amount of quota that can be owned by any one company or individual. Unfortunately, restrictions on the property right may constrain low cost fishers, who do not exercise market power, from acquiring as greater a share of the quota holdings as they would like[7].

Fishery managers can employ various means to assess the competitiveness of the quota market and the market for fish. The easiest measures to implement are concentration ratios that provide an index of market share of firms. The so-called Herfindahl-Hirschman index (HHI) is a commonly used measure in various industries and is defined by equation (1).

$$\text{HHI} = \sum_{i=1}^{n} S_i^2 \qquad (1)$$

where $S_i$ is the market share of firm i and, if only one firm exists in the market, the index has a value of unity[8]. The problem with a concentration ratio is that the existence of a relatively small number of firm in the market does not, by itself, imply market power.

An alternative to measuring firm shares is to monitor the prices and trades of quota and fish. If the domestic price of fish, for example, is not responsive to increases, but is highly sensitive to decreases in the export price, it provides some evidence of the exercise of market power by fish processors. Conversely, if quota prices (especially lease prices) do not appear to increase with rises in the landed price of fish, but fall with declines in output prices, it provides some evidence of market power in the quota market.

An important question to address is, what should be done in response to evidence of market power? The answer will depend on many factors including the jurisdiction of where the fishery is located. Whatever the approach used to make markets more competitive, regulators should be aware that sometimes the remedy, such as restrictions on the property right, may be worse than the problem itself.

*C. Management Costs and Quality*

Economic monitoring of fisheries requires that an estimate of the costs associated with fisheries management be obtained. Some management activities that are required under CAC will be replaced with new, and possibly more costly, management activities under ITQs. For instance, in a CAC fishery managers may regulate the gear used, the season length, the location of fishing, as well as vessel numbers and their size.

Fewer adjustments may be required under ITQs, however, introducing ITQs and ensuring that they represent an exclusive and durable property right often involves extra management costs in terms of monitoring and enforcement. Although some management costs may rise with ITQs, other expenses may decline, such as the transactions costs associated with regulating inputs of fishers. Moreover, a switch to ITQs may be associated with changes in management responsibilities and, in some cases, the costs of some activities (such as monitoring and enforcement) may be transferred from the regulator to the fishers themselves.

To ensure the net benefits associated with ITQs include all costs, the extra expenses in managing ITQs should be calculated. In some ITQ fisheries, the management costs are borne by the fisheries regulator and apportioning costs across fisheries can be problematic. Although fixed costs can be difficult to apportion, the extra costs associated with monitoring landings and quota holdings should be identified. In some cases, these costs are fully-funded by the fishers themselves and the expenses are easily obtainable. Whatever the cost sharing arrangement, the expenses associated with fisheries management should be regularly recorded.

In addition to ensuring that the extra costs associated with ITQs are accounted for, some effort should be made to assess changes in the quality of management. For example, a shift to ITQs has encouraged some fishers to improve the quality of stock assessment and this has been accompanied with higher management costs. Measuring changes in quality is a difficult undertaking but annual surveys of management performance, as perceived by fishers, would provide an index over time of the perceived quality of management, as would regular audits of management performance.

*D. Efficiency*

An often-stated attribute of ITQs is that they improve economic efficiency. Despite the goal, measures of efficiency are probably the least understood and are rarely undertaken in fisheries. The term efficiency has been interpreted in a number of ways in fisheries. A precise definition describes technical inefficiency as the overutilization of all inputs, allocative inefficiency as the utilization of inputs in wrong proportions relative to factor prices, and scale inefficiency as production at an inappropriate level of output. Economic inefficiency may arise from technical, allocative or scale inefficiency, or any combination thereof [9]. Further details of the different measures of efficiency, including individual factor measures of technical and allocative efficiency, are provided in Grafton Squires and Fox (1999).

Various methods exist for deriving individual efficiency measures. Two of the principal approaches include a form a mathematical programming called Data Envelopment Analysis (DEA) and econometric approach that estimates a stochastic frontier. In both cases, the production, cost or profit frontier of firms is unknown and is estimated using data from a sample of fishers.

Data Envelopment Analysis Methodology

The data envelopment analysis (DEA) approach is non-parametric and does not impose a functional form on the specification of the frontier but, unlike the stochastic frontier, supposes that deviations from the frontier are due to inefficiencies alone. The methodology uses cross-sectional or panel data to construct a piece-wise frontier and can be used where there exist multiple outputs and inputs.[10]

To illustrate the approach, a ratio of all outputs over all inputs for a given observation i can be defined and weights assigned for each output and input, i.e.,

$$u^T y_i / v^T x_i$$

where $(u^T, v^T)$ is the output-input weights for observation i. The mathematical programming model requires that the weights of u and v are maximized, given the constraint that the weights are nonnegative and that efficiency measures for all observations are equal to or less than one, where an efficiency measure of unity is at the frontier. If the inputs weights are normalized such that $v^T x_i = 1$, the mathematical program is called the “multiplier” problem and output and input weights are chosen to solve (2).

Maximize $u^T y_i$

subject to

$$u^T y_k / v^T x_k \leq 1, \qquad k=1, 2, \ldots, N \qquad (2)$$

$$v^T x_i = 1,$$

$$u, v \geq 0$$

In practice, the dual to the problem (2) is solved because it involves fewer constraints and is called the "envelopment" problem. The problem is solved N times and a scalar $\theta$ is calculated for each observation, where $\theta_i = 1$ implies that firm i is technically efficient and on the frontier.

The DEA approach is relatively easy to apply provided there exists individual fisher data on outputs and inputs. Moreover, it can be extended to include variable returns to scale and, if price data is available, individual measures of allocative efficiency may also be derived. For example, if costs and earnings data are available, managers can calculate allocative and technical efficiencies under the assumption of cost minimization for a given level of landings. Calculations of these efficiency measures are relatively straightforward if one of the several packages especially designed for this purpose are used[11].

Stochastic Frontier Methodology

An alternative to the DEA approach to deriving efficiency measures is to estimate a stochastic frontier using regression techniques. Unlike DEA, the stochastic frontier does not presume that deviations from the frontier are due exclusively to inefficiencies and, instead, assumes that deviations can be caused by stochastic events (such as bad weather, luck, etc.), as well as inefficiency, at the vessel level. By contrast to the DEA, the stochastic frontier approach requires the specification of a functional form and is limited to those situations where there is a single dependent variable.

The stochastic frontier can be defined with output, revenue, cost or profit as the dependent variable, depending on the data available and what measure is desired. If we define $y_i$ as the dependent variable, $x_i$ as a vector of inputs, the stochastic frontier is defined by (3).

$$y_i = f(x_i;\beta)\exp(\varepsilon_i - \mu_i) , i = 1, 2, \ldots, N \qquad (3)$$

where $\beta$ is a vector of parameters to be estimated, $\varepsilon_i$ is a random disturbance term, assumed to be $N(0,\sigma^2_\varepsilon)$, and which accounts for random shocks to the production process beyond the control of fishers, and $\mu_i$ is assumed to be independent of $\varepsilon_i$ and a non-negative random variable associated with technical inefficiency[12]. In the case of a fishery, the frontier should also include a technological constraint that reflects changes in the resource stock that, in turn, influences the output, returns and costs of fishers.

The $\mu_i$ term is commonly assumed to be distributed as a exponential, half normal, truncated normal or a two parameter gamma and the frontier is usually estimated using maximum likelihood. A measure of technical efficiency, as shown in (4), for each observation ($TE_i$) is defined as the ratio of observed to maximum feasible $y_i$ where $y_i$ is observed output,

$$TE_i = y_i / f(x_i;\beta)\exp(\varepsilon_i) = \exp(- \mu_i) \qquad (4)$$

The random disturbance $\varepsilon_i$ can be eliminated from efficiency measures by subtracting it from observed output such that $y_i - \varepsilon_i = \hat{y}_i - \mu_i$ where $\hat{y}_i$ is predicted output and, by definition, $y_i - \hat{y}_i = \varepsilon_i - \mu_i$ such that $\varepsilon_i = y_i - \hat{y}_i + \mu_i$[13]. In this approach, the focus is on the estimation of $TE_i$ and the parameter estimates of $\beta$ are of a lesser interest, as are estimates of elasticities of substitution derived from the frontier[14].

Most of the functional forms used in estimating a stochastic frontier are linear in logarithms in the dependent variable and inputs. Where input price data are available, the stochastic frontier approach can also be used to derive a measure of economic efficiency by estimating a cost frontier (or production frontier) self-dual to a production function (or cost function). Measures of economic efficiency may be obtained from $\mu_i$ in the cost frontier and measures of technical efficiency using $\mu_i$ from the production frontier. Measures of allocative efficiency can then derived by noting that allocative efficiency is the ratio of economic efficiency over technical efficiency.

Assessing Changes in Efficiency

Measuring changes in efficiency that are attributable to management reform raises a number of challenges. In particular we would expect that ITQs will affect the location of firms relative to the production set, as well change its shape and location. For example, relaxing gear restrictions under ITQ management should enhance individual firm efficiency, which implies that firms will be located closer to the frontier of the producible set.

Both the DEA and stochastic frontier methodologies can be used to measure ex-post changes in efficiency due to variables outside of the short-term control of fishers, such as the effects of relaxing management constraints, or changes in the size of a vessel. One approach to assessing changes in efficiency is to regress the estimated individual efficiency measures against so-called environmental variables that can be either categorical or continuous.

This two-stage approach requires that Tobit regressions be estimated to account for the censoring of the technical, allocative, and economic efficiency measures at zero and one. Effects of a shift in the management regime, such as the introduction of ITQs, can be evaluated with dummy variables for the year the regime changed provided that data is available from before and after the change took place. The effects of the regime shift can be evaluated by Wald tests of the null hypothesis of no change in efficiency between two time periods. For example, using two dummy variables, $D_{before\ ITQs} - D_{after\ ITQs} = 0$, tests the null hypothesis of equal efficiency for vessels before and after ITQs were introduced into the fishery. If the chi-square value is significant for an efficiency measure (given a single linear restriction and hence one degree of freedom), the null hypothesis of equal efficiency is rejected[15].

*E. Equity*

Equity issues of concern to fishers include how ITQs are initially allocated, the consequences of quota trades on the market structure in the fishery, and the effects of ITQs on returns to labor and among quota holders. Equity is important because fishery managers often place considerable importance upon the distribution of income and wealth among fishers, and because it may affect both the sustainability of the resource and efficiency of the fleet. For instance, given that enforcement is costly, a group of fishers who feel the initial allocation of ITQs was unfair may be able to disrupt or subvert the harvesting rules necessary to ensure the proper management of the fishery. Moreover, given uncertainty over the state of the fishery and future quota prices, the initial allocation may affect the equilibrium quota-trading outcome[16].

The equity issue is of greatest concern when assigning the initial allocation of quota. The common practice has been to base initial allocations on the past harvests and/or characteristics of vessels and thus assign the rights to vessel owners. Alternative arrangements could also include allocations to crew or communities or the auctioning of the rights. After ITQs have been introduced, equity concerns can be addressed in a number of ways including the capture of rent from quota holders with a portion assigned to persons deemed to have been losers in the new management regime[17].

An important concern in fisheries is the income distribution among fishers. Income inequality measures should, in principle, satisfy the criteria of anonymity (it should not matter who earns the income), population (the size of the population should not affect inequality), scaling/relativity (only the relative income of individuals should matter) and the Dalton principle (when comparing two different income distributions, if one can be derived from the other by a series of regressive transfers then it is less equal than the other)[18]. Where costs and earnings data for vessels and remuneration data of the skipper and crew exist, a useful measure of inequality can be derived from the Lorenz curve which plots the relationship between cumulative income or wealth or quota holdings (on the vertical axis) against the cumulative population of fishers or quota-holders (on the horizontal axis). If every person has the same income or wealth, the curve is represented by a $45^0$ line, and the more unequal the distribution the greater area between the Lorenz curve and the $45^0$ line. When comparing different income distributions, provided the Lorenz curves do not cross, this approach satisfies the four criteria of inequality measures.

Quantitative measures of inequality can also be obtained from the Lorenz curve. For instance, the Gini coefficient measures the area between the Lorenz curve and the $45^0$ line relative to the entire area below the $45^0$ line, where a measure of 0 indicates that all individuals have identical incomes. Another measure of inequality that requires data by individual is the coefficient of variation, defined as the standard deviation of income of the population divided by the mean income. If detailed income or wealth data is only available by groups (such as vessel owners or crew members) an alternative measure of inequality is to estimate Kuznets ratios where the ratio of income earned by crew can be compared to income earned by skippers or vessel owners.

*F. Productivity*

Productivity measures provide a useful tool for evaluating economic and other changes in fisheries. Measures of productivity are usually defined as the total output or harvest as a ratio to the most important input. For example, labor productivity in a fishery could be defined as total landings of fish per crew-member, or vessel productivity could be defined as total harvest per vessel. Different productivity measures, however, need not move in the same direction such that labor productivity may be declining contemporaneously with an increase in vessel productivity.

An alternative and broader measure is TFP which is simply the ratio of the ratio of output(s) to all inputs at a point in time *t*, i.e.,

$$\text{TFP}_t = \text{Output Index}_t \,/\, \text{Input Index}\ t \qquad (5)$$

where the output and input indices may be formed from data for one vessel over time, from many vessels for a point in time or from many vessels over time. The choice of the index for the outputs and inputs has been subject of much research[19]. A useful index with theoretically desirable properties is the Fisher Ideal Index (FII) and is defined as the geometric mean of the Paasche and Laspeyeres indices, i.e.,

$$\text{FII} = \sqrt{P \times L} \qquad (6)$$

where the Paasche price index (*P*) uses base period quantities as weights and the Laspeyeres price index (*L*) uses current period quantities as weights. In the case where multilateral comparisons are required (across vessels) the FII, or any other index, should be made transitive using an approach called the EKC method[20].

Changes in TFP over time can be calculated by defining the ratio of TFP over time[21],

$$TFP_{t+1} / TFP_t = (\text{Output Index}_{t+1} / \text{Output Index}_t) / (\text{Input Index}_{t+1} / \text{Input Index}_t) \quad (7).$$

The index of the growth in TFP can be defined as a residual, in a discrete form, between the rate of growth of real product and the rate of growth of real factor input as per equation (8),

$$(TFP_{t+1} - TFP_t) / TFP_t = (\text{Output Index}_{t+1} - \text{Output Index}_t) / \text{Output Index}_t - (\text{Input Index}_{t+1} - \text{Input Index}_t) / \text{Input Index}_t \quad (8).$$

The method defined by (8), in a continuous form, is a so-called growth accounting approach to measuring changes in TFP over time. The approach, when applied to fisheries, must also explicitly account for the resource stock that should be treated as a technological constraint in the production process of firms[22].

A fundamental problem of productivity is how to interpret changes over time. In other words, are productivity increases due to technical change? Or, are they due to changes in efficiency? Or changes in the resource stock? An approach that tries to decompose productivity changes is the Malmqvist productivity index (MPI). The MPI measures TFP as the ratio of the distance to a production frontier, for each observation, under a common technology. The distance measure may be defined as an output distance function on the output set P($x$) for the input vector $x = (x_1, x_2, \ldots, x_n)$ and output vector $y = (y_1, y_2, \ldots, y_n)$, as per equation (9),

$$D_0(x, y) = \min \{\theta : (y/\theta) \in Y(x)\} \quad (9)$$

where the distance function $D_0(x, y)$ has the value of unity if the observation is on the frontier[23].

The MPI can be constructed using distance functions. In the two period case, the index is defined by equation (10),

$$M_0(y^{t+1}, x^{t+1}, y^t, x^t) = [D_0^t(x^{t+1}, y^{t+1}) / D_0^t(x^t, y^t) \times D_0^{t+1}(x^{t+1}, y^{t+1}) / D_0^{t+1}(x^t, y^t)]^{1/2} \quad (10)$$

where $D_0^t(x^{t+1}, y^{t+1})$ represents the distance of the observation in period *t+1* to the best practice defined by period *t* and $D_0^{t+1}(x^{t+1}, y^{t+1})$ represents the distance of the observation in period *t+1* to the best practice defined by period *t+1*.

The MPI can be equivalently written as equation (11),

$$M_0(y^{t+1}, x^{t+1}, y^t, x^t) = E\,[D_0^t(x^{t+1}, y^{t+1}) / D_0^{t+1}(x^{t+1}, y^{t+1}) \times D_0^t(x^t, y^t) / D_0^{t+1}(x^t, y^t)]^{1/2} \quad (11)$$

where $E = D_0^{t+1}(x^{t+1}, y^{t+1}) / D_0^t(x^t, y^t)$ and is the change in technical efficiency between period *t* and *t+1* defined as the ratio of the technical efficiency of the observation at *t+1*, relative to the best practice frontier at *t+1*, to the technical efficiency of the observation in period *t*, relative to the best practice frontier in period *t*. In equation (11), the MPI consists of a measure of efficiency change defined by E and a measure of technical change defined by a geometric mean in the shift in the technology, or best practice frontier over time. An overall improvement (decline) in technical efficiency, technical change and productivity over time is represented by an increase (decrease) in E, the square root of the second term in (11) and the MPI.

The MPI can be calculated in fisheries provided there exists individual data on inputs and outputs. Specialist software packages are available if a DEA methodology is used[24]. Alternatively, a stochastic production frontier may be estimated that includes a time trend to capture technical change in the frontier, and parameters to estimate, that explain how technical efficiency varies over time. Both approaches, however, require multiple observations in each time period to construct a frontier and that requires data that is frequently unavailable in fisheries. Where such data is lacking, an index of TFP may be derived from as few as two observations (one vessel over two time periods) provided that both price and quantity data is available to aggregate inputs and outputs (using a FII or some other index). In this approach, a frontier or best practice technology is not estimated and, instead, a measure of productivity change is defined as a ratio of an output and input index. The deficiency of this more straightforward approach is that it does not decompose productivity changes into changes due to technical efficiency and technical change.

### *G. Multi-Product and Multi-Input Issues*

Increasingly, ITQs are being applied to multi-species fisheries and the issues of substitutability among species and the nature of the harvesting technology are important to ensuring effective management[25]. For example, introducing ITQs on a subset of species requires an understanding of the possible substitution between ITQ and non-ITQ species, and the extent to which harvesting processes are distinct or joint among different species.

To better understand the nature of the harvesting process in multi-species fisheries, cost, revenue and profit functions may be estimated[26]. Under certain regularity conditions, the production frontier of vessels may be constructed from the dual (cost, revenue and profit) functions and the output supplies and input demands can be derived using the Envelope Theorem. Thus the dual functions provide a means of estimating the complementarity or substitutability among several outputs and inputs. Moreover the dual functions, and the corresponding input demand and output supply functions, can be used to derive price elasticities and thus obtain a measure of the responsiveness of the fleet to changes in prices.

The choice of which dual function to estimate depends on data availability and the nature of the fishery. For instance, a cost function requires the assumption that the outputs of fishers are constrained in some way. Where costs are unavailable, but price and output data exist, a revenue function may be estimated to derive output supply functions. If cost, price and output data is available a profit function, or a restricted profit function where one or more inputs are fixed, may be estimated. Another important issue is the choice of the functional form of the dual function to be estimated. Wherever possible, functional forms should be fully flexible such that they do not constrain the values of the elasticities derived from the input demands or output supplies[27].

A functional form that has been applied in multi-species fisheries and which is often less demanding in terms of data requirements than estimating cost or profit functions, is the generalized Leontief revenue function defined by (12),

$$R(P;Z) = \sum_i \sum_j \beta_{ij} (P_i P_j)^{1/2} Z + \sum_i \beta_i P_i Z^2 \tag{12}$$

where $P_i$ is the price of species i and $Z$ is a composite input[28]. Using Hotelling's Lemma the input-compensated supply function may be derived and hypotheses tested, such as whether the harvesting function is non-joint in inputs or separable in inputs and outputs.

If data is unavailable on an individual fisher basis, measures of inputs and outputs[29] can be constructed using aggregate data over time. Thus, for example, a large increase in landings in a non-ITQ species, following the introduction of ITQs in a multi-species fishery, indicates some degree of substitutability among the different species.

### *H. Capacity*

Capacity may be defined as the ability of a firm, in the short-run, to produce the maximum level of output without any restrictions to the amount of variable inputs that can be used. Capacity in fisheries has been defined as the maximum level of landings or output that can be achieved in a given period of time if the fishing fleet is fully utilized, and given the current state of technology and the resource stock.

In the fisheries literature, capacity is often related to one measure of the inputs used by fishers, usually the gross registered tonnage or the number of vessels in a fishing fleet. Programs designed to reduce overcapacity have focused on reductions in capital stock measures. In reality, fishers use a variety of fixed and semi-fixed inputs and a mix of variable inputs that may be used in varying proportions with the fixed inputs. Moreover, in many fisheries, a range of outputs are produced each of which may be derived from their own unique resource stocks. Thus, measures of capital utilization and capacity utilization will not, in general, coincide in fisheries and any measure of capacity must be defined in terms of sustainable levels of the resource stocks.

The DEA methodology can be used to calculate capacity output, given the variable factors are unbounded, and the fixed factors, resource stock and technology constrain output[31]. A drawback of the DEA approach is that it assumes deviations from the frontier arise from inefficiency and not stochastic or random events. However, DEA does not impose an underlying functional form (as is the case with econometric or parametric methods), is relatively easy to apply, only requires data on inputs and outputs and can provide a measure of capacity output for each species, as well as overall measures of fleet capacity[32].

An alternative to the DEA methodology is to assume that firms maximize profit and to estimate a restricted profit function. In this econometric approach, measures of capacity utilization can be derived which define the output gap that exists when actual output differs from capacity output (or alternatively the cost gap in a dual problem). In this approach, measures of capacity utilization provide an indication as to whether the current level of the fixed factor is in long-run equilibrium[33].

Where individual data on outputs and inputs are unavailable, alternative measures may be derived. An easy-to-compute measure is fleet hold capacity that requires data on the number of vessels, their hold capacity (or some other measure of capital, such as vessel length) and the number of full hold trips per fishing season. Using this data, a maximum potential fleet hold capacity in tons of fish can be derived. The ratio of the total allowable catch (TAC) to maximum potential provides a measure, albeit of limited value, of aggregate capital (or more precisely hold) utilization and provides an indication of the potential to increase the total harvest in the absence of major vessel expenditures.

A slightly more sophisticated approach involves estimating a maximum potential output using time series data from a fishery, where the potential output less actual output is interpreted as a measure of excess capacity. Alternatively, a composite input in the harvesting process, such as gross registered tonnage (GRT) may be multiplied by a measure of technological efficiency. Aggregate measures for a fleet may then be obtained by multiplying different vessel types by their average GRT, and technology efficiency, to derive a measure of capacity output of the composite input[34].

*I. Sustainability*

A major concern of fishery managers is the potential for ITQs to encourage harvesting practices that may be deleterious to the sustainability of the fishery[35]. Quota busting, or the illegal landing of fish in excess of quota-holdings, is a particular concern and requires an adequate system of monitoring of landings. The monitoring may include visual inspection, or the weighing of landings at specified ports, and the auditing of fish deliveries to fish processors and the reconciliation of quota-holdings and overall landings. Although quota busting has, at one time or another, existed in most ITQ fisheries, managers and the fishers themselves have developed effective systems to monitor landings and reconcile harvest with quota shares.

A much more difficult problem to assess is the potential of fishers to "highgrade" where smaller or less desirable fish are thrown overboard so that the revenue per unit of quota is maximized[36]. Further, fishers who may not wish to land certain fish, or have difficulty reconciling their catches to existing quota holdings, may chose to dump fish at sea. The dumping or discarding of fish in turn may compromise the sustainability of the resource, especially if the discards are not estimated in overall fishing mortalities.

The most effective (and most expensive way) to prevent discarding is to have on-board inspectors. Such an approach has been highly successful in large offshore ITQ fisheries where returns are sufficient to cover the costs of an on-board observer. In many ITQ fisheries, however, this solution is not financially viable and alternative measures are required. For example, if discarding is perceived to be a problem, observers may be placed on a small number of vessels during the season and the mix of species and characteristics from the harvest of such vessels may be compared to vessels without inspectors. Hypothesis tests can then be applied to evaluate whether the harvest characteristics of the vessels, with and without observers, come from the same distribution.

A more technical approach to the potential discarding problem involves the use of video cameras and recorders fitted to vessels for visual inspection of a vessel's harvest, and subsequent comparison to the fish landed on shore. Whatever the approach, an on-going system of monitoring and evaluation is required to ensure that harvesting practices do not compromise the sustainability of the fishery.

## III. Data Requirements

The ideal source of economic data on fisheries is a comprehensive time series of individual vessel data of the entire fisher population that includes prices and quantities of all inputs and outputs per fishing season. Unfortunately, such data does not exist for any ITQ fishery and, at best, researchers and managers have access to costs and earnings data of a sample of vessels at different points in time. At worst, the only data available may be aggregate information on landings and the number of vessels---information that provides little opportunity for in-depth and meaningful economic analysis.

If ITQ fisheries are to be managed effectively, data on individual fishers over time are required. The economic data collection, and its evaluation, should be an integral part of fisheries management. Compared to the costs of monitoring and enforcement, the expenses associated with collecting and evaluating such data from a sample of fishers are relatively small. The data collected should include individual vessel data with details on the skipper and crew characteristics, ownership, vessel and gear characteristics, fishing and non-fishing income, gear and maintenance costs, debt, licence and quota costs, and revenue, cost break-downs and input use (if possible) by species. Confidentiality of the data must be ensured, but the unit of analysis must be kept at the firm level to fully evaluate the economic performance of fishers.

In ITQ fisheries, records are also maintained on quota holdings and permanent trades and, sometimes, price data on quota traded that provide insights into the characteristics of quota owners and vessels that may be expanding their operations or exiting the fishery. Such data, coupled with log-book information, may also be used to track economic performance of individual fishers and the fleet.

## IV. Concluding Remarks

Increasingly, regulators are using individual transferable quotas to address the common-pool problems inherent in fisheries. Despite their increasing use, very few studies exist that track the changes in economic performance of fishers with private harvesting rights.

To address this problem, and improve the management of ITQ fisheries, the paper reviews different methodologies to assess the economic performance of fishers in terms of profitability, competitiveness, management quality and costs, efficiency, equity, productivity, output and input interactions, capacity and sustainability. A guide to these methodologies, and how they may be applied, should prove useful to researchers and fishery managers interested in improving the economic performance of individual transferable quota fisheries.

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**Endnotes**

1. One of the earliest reviews was by Muse and Schelle (1989). Reviews of several different fisheries appeared in the edited volume entitled *Rights Based Fishing* by Neher, Arnason and Mollett (1989).
2. One of the latest conferences was the November 1999 conference on rights-based fishing in Fremantle, Australia.
3. See, for example, Squires and Kirkley (1995) and Squires and Kirkley (1996). These papers address the issue of how to calculate an expected market equilibrium for quotas and the economic rents and gains in efficiency associated with trading using inverse derived demand functions.
4. See Lindner et al. (1992).
5. Such an approach was used by Herrmann (1996) when he assessed the output price increases which arose from the introduction of ITQs in the British Columbia halibut fishery.
6. Anderson (1991) described the consequences of market power in an ITQ quota market.
7. Evidence from at least one ITQ fishery, however, suggests that the introduction of ITQs into a fishery, if accompanied with a significant increase in the length of the fishing season, may increase the market power of harvesters at the expense of fish processors. See, for example, Love et al. (1995).
8. For further details on concentration ratios, consult Scherer (1979).
9. For a useful review of the different types of inefficiency, see Forsund et al. (1980).

10. A concise review of the methodology is provided by Lovell (1993). More detailed descriptions of DEA include Norman and Stoker (1991) and Coelli et al. (1998).
11. Software to use the DEA methodology is available from several different sources. A DOS based program available free to academic researchers is DEAP can be sourced from Tim Coelli at tcoelli@metz.une.edu.au. A WINDOWS based program called OnFront is available from Shawna Grosskopf at Shawna.Grosskopf@orst.edu.
12. If a cost frontier is specified then the error tem $\mu_i$ must be added rather than subtracted from (3).
13. See Schmidt (1985) and Grafton, Squires and Fox (2000) for further details.
14. Two econometric packages that can be used to directly estimate stochastic frontiers are FRONTIER 4.1, available from Tim Coelli at tcoelli@metz.une.edu.au, and LIMDEP authored by William Greene.
15. See Grafton, Squires and Fox (2000) for an example and further details.
16. The fact that the initial allocation of rights can affect the equilibrium outcome has it origins in Coase (1960). Grafton (1992) and Cunningham (1994) address this issue in fisheries and Weninger and Just (1997) develop a model that illustrates how fishers may delay their exit from a fishery under price uncertainty in the expectation of higher prices in the future.
17. Grafton (1995) reviews the issues of rent capture in ITQ fisheries.
18. For a nice discussion on these issues, see Ray (1998, chapter 6).
19. Coelli et al. (chapter 4, 1998) provides a useful discussion on the different types of indices that can be used.
20. See Coelli et al. (pp. 84-87, 1998) for details.
21. Grosskopf (1993) provides an excellent introduction to the measurement of productivity and efficiency.
22. Squires (1992) in one of the first comprehensive papers on productivity in fisheries addresses the issue of the resource stock and productivity measurements.
23. The output distance function is the reciprocol of the output-based measure of technical efficiency. Further details are provided in Fare et al. (1994).
24. Two packages which are can be used are DEAP and OnFront (*supra* note 11 above).
25. Squires et al. (1998) provide a useful review of the management issues of ITQ fisheries.
26. A definitive reference on the estimation of the theory and estimation of these functions is provided by McFadden (1978).
27. Many different flexible functional forms can be estimated. A review of some of these forms is provided by Fuss et al. (1978).
28. This function was first applied in fisheries by Kirkley and Strand (1988) and was used by Squires and Kirkley (1991) to provide management insights about ITQ fisheries. Squires and Kirkley (1991) and Squires and Kirkley (1996) provides a useful framework for improving the management of multi-species fisheries.
29. Squires (1984) provides an excellent review of the hypotheses that can be tested from a restricted profit function estimated using fisheries data.
30. For a definitive review and explanations and examples of how to apply the various approaches to measuring capacity in fisheries, consult Kirkley and Squires (1999).
31. The approach was developed by Färe, Grosskopf and Kokkelenberg (1989).
32. An application of the approach, applied to a multi-product ITQ fishery, is provided in Dupont et al. (1999).
33. The approach was developed in fisheries by Squires (1987) and Segerson and Squires (1990; 1993).
34. Kirkley and Squires (1999) describe in detail these so-called measures of excess capacity.
35. Several authors have reviewed the potential problems associated with ITQs. One of the most widely cied critique of ITQs is Copes (1986).
36. See Anderson (1994) and Arnason (1994) for further details.
37. For further details of the ICES Study Group see ICES (1997).