PRIVATE PROPERTY AND ECONOMIC EFFICIENCY:

A STUDY OF A COMMON-POOL RESOURCE

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ABSTRACT

The British Columbia halibut fishery provides a natural experiment of the effects of "privatizing the commons". Using firm-level data from the fishery two years before private harvesting rights were introduced, the year they were implemented and three years afterwards, a stochastic frontier is estimated to test for changes in technical, allocative and economic efficiency. Despite some improvement in short-run measures of cost efficiency, overall the fishing fleet still remains well below the best practice frontier. The relatively few short-run efficiency gains are attributed to deficiencies in the property right and the possibility that fishers may require several years to optimize their operations. By contrast, the results indicate an immediate and significant increase in producer surplus and unit rents which are directly attributable to the privatization. The results suggest that if the full benefits of privatization are to be realized, careful attention must be given to properly specifying all the characteristics of the property right.

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"For that which is common to the greatest number has the least care bestowed upon it. Everyone thinks chiefly of his own, hardly at all of the common interest; and only when he is himself concerned as an individual."
Aristotle, *Politics*, Book 2, Chapter 3, p. 27.

I. INTRODUCTION

The structure of property rights has long been considered one of the most important factors affecting economic development and efficiency. For common-pool resources, where yields are rivalrous and use is only partially excludable, the absence of controls over access leads to the "Tragedy of the Commons". Fisheries provide the classic case of open access (Gordon 1954) where market failures arise, in part, because agents are unable to contract to exclude others and prevent rent dissipation (Cheung 1970).

One solution to the problems of open access is the "privatization of the commons" or the creation of individual private property rights for common-pool resources. This approach is consistent with the view of Demsetz (1967), who argued that the exploitation of common-pool resources requires individual property rights to minimize costs. If transactions costs are zero, there is no strategic behavior, perfect information, and the distribution of assets does not affect the marginal valuation of resources, the Coase Theorem implies that private property rights ensures efficiency. Limitations to the dimensions of private property rights, however, may result in firms optimizing such that their costs may not be minimized for given levels of output (De Alessi 1983). Despite the growing use of private property to help solve common-pool externalities, such as air pollution, global warming and the overharvesting of fish stocks, few empirical studies exist which test for changes in efficiency due to private property rights.[1] Instead, the literature has used comparisons, qualitative evidence, and descriptions to evaluate whether the theoretical benefits of private property have been realized.[2] By contrast, this paper uses data from a natural experiment involving a common-pool resource to analyze the changes in a fishery following the introduction of private harvesting rights. Most importantly, the paper examines how specifying the characteristics of property rights affects the efficiency and producer surplus of firms. The results provide insights into how private rights and their characteristics affect firm behavior and the expected benefits of "privatizing the commons".

II. PROPERTY RIGHTS AND EFFICIENCY

Property rights are the societally accepted rights of individuals or groups of individuals to exploit assets for their benefit with at least a partial right to exclude others. These rights may be described by their divisibility, exclusivity, transferability, duration, quality of title, and flexibility.[3] If one or more of these characteristics is attenuated, the benefits of incentive-based approaches for managing common-pool resources may be diminished.

Divisibility describes the extent to which the right can be partitioned, such as the division of surface and mineral rights for land. Exclusivity encompasses the notion of security and describes the ability to restrict the yield and the right of others to use an asset. Transferability refers to the ease by which owners may trade, gift or bequeath the property right. Duration encompasses the notion of how long the property right exists, such as whether it expires at the end of every year or whether it is valid in perpetuity. Quality of title represents how well specified is the property right. It includes whether the right is legally and formally recognized so that it may be used, for example, as collateral for a loan or other purposes. Flexibility, the last characteristic, refers to the ability of the property right to accommodate changes in the resource and circumstances of the owner(s).

In the case of fisheries, various types of property rights with different characteristics have been used to address common-pool resource externalities.[4] In response to past failures in fisheries management, regulators are increasingly turning to individual harvesting rights, often called individual transferable quotas (ITQs), to increase the rent from the resource. ITQs, in various forms, have been introduced in three U.S. fisheries and such countries as Canada, New Zealand, Iceland, Australia and the Netherlands (Grafton et al. 1996). The principal advantage of individual harvesting rights is greater exclusivity in exploitation. Individual harvesting rights are not, however, a complete property right. For instance, ITQs only provide a right over the flow of the resource and not the stock of fish, and thus do not give a property right over the ocean environment. Further, in all ITQ jurisdictions some limits have been placed on the characteristics of the property rights, especially their duration, transferability and divisibility.

Individual harvesting rights have the potential to change both the costs and revenues of fishers. In the short run, the creation of an exclusive property right may mean that other regulations designed to restrict the harvest of the fishing fleet may be redundant. Thus, with individual output controls, the length of the fishing season may be increased. Coupled with transferability of the property right, harvesting rights should also help fishers to adjust their scale of operations to maximize their profits. A reduction in the "race to fish", because of ITQs, can reduce spoilage and mishandling of fish which is common in fisheries with very restricted fishing seasons and thus has the potential to increase the value of the product landed by fishers and their producer surplus. Depending upon the fishery, fewer regulations on harvesting practices may also enable fishers to better adjust their mix of inputs to minimize costs for a given level of output. Given that the gear and vessels form non-malleable capital in many fisheries, ITQs also offer the long-run potential benefit that fishers can adjust their vessels and equipment to an optimal size. Thus, depending on the former restrictions on inputs, one might expect ITQs to lead to improvements in allocative efficiency (the desirable mix of inputs) and in technical efficiency (the desirable level of all inputs) over both the short and long run.

III. THE COMMON-POOL RESOURCE

To test for changes in firm behavior, efficiency and producer surplus following the introduction of private property rights, we examine the British Columbia (BC) halibut fishery. Since 1923 the Pacific halibut fishery has been cooperatively managed by the International Pacific Halibut Commission (IPHC), a body established by the United States and Canada. The IPHC sets area-specific fishing seasons, the total catches for all the fishing regions along the Pacific coast, and minimum size limits of the fish allowed to be caught.

Following a protocol between the two governments in 1979, the harvesting of halibut in Canadian waters has been restricted to Canadian fishers and the number of vessels limited to 435, the number of halibut fishing licences. Limited transferability of licences is permitted provided that the vessel to which the licence is being transferred is no more than 10 feet longer in size. The "stacking" of licences, however, is prohibited and only one halibut licence per vessel is permitted. In addition to halibut fishing licences, the fishery has also been regulated by a total allowable catch (TAC) for the fleet, a limited fishing season, restrictions on the type of gear which can be used to harvest halibut and minimum fish sizes. Most of the halibut fleet also participates in other ground fisheries and the salmon fisheries.

Halibut are a long living and highly migratory species found from northern California to Alaska and are principally caught by longline gear. Longlining involves the setting of baited hooks laid at depths of 30 to 300 meters that are attached to “skates”, or shorter fishing lines which are connected to a main fishing line and a series of buoys. After setting the lines, which are left to “soak” for between 6-10 hours and sometimes up to 24 hours, the skates and fish are hauled on board. The harvested fish are gutted, after first being stunned on the head, and are packed in ice and delivered directly to processors. Captains can alter the level and composition of catch by deciding where to fish, the season and depth of fishing, length of lines, type of bait, hook size, spacing of hooks on the lines, and the time the gear spends in the water. Catch size and species composition vary with expected halibut prices, biological abundance, seasonality, and other factors.

A. The Derby Fishery

Technological advances such as circle hooks, snap-on gear, automatic baiting machines, hook disgorgers, and improved electronics to locate fish substantially increased the productivity of the halibut fleet throughout the 1980s. Improvements in gear, coupled with an increased number of crew per vessel and the use of more fishing gear and a longer time spent fishing per fishing day, resulted in the harvesting of almost 50 percent more fish in 1990 (with a fishing season per vessel of 6 days) than was caught a decade earlier when the fishing season was 65 days long.[5] Increased fishing pressure led the IPHC to reduce the length of the fishing season throughout the 1980s to try and prevent the TAC of halibut from being exceeded. Relatively high returns, an increasing TAC, and an increasing number of transfers of halibut licences also helped to increase the number of active fishers. Table 1 shows that the number of active vessels increased from 333 in 1980 to 435 in 1989, the total number permitted by the regulator, while the total catch increased over most of the decade.

The increased productivity and reduced length of the fishing season resulted in a 12-fold increase in the average catch per day for the whole fleet from 1980 to 1990, and a tripling of the average landings per trip per vessel (Porter 1996). This increased fishing intensity sometimes resulted in skates from different vessels being laid over the same area which increased the damages to lines and resulted in "ghost fishing", whereby lost fishing gear continues to catch fish. A reduced fishing season, which was just 6 days long in 1990, encouraged fishers to catch halibut in unfavorable weather conditions and reduced safety at sea. A short fishing season also provided the incentive to fishers to maximize their landings over just few days, which in turn compromised product quality. In addition, catching and processing the entire catch in just a few days limited the marketing opportunities and the bargaining power of fishers to negotiate higher prices for their product from processors.

A drop in the total catch from 1988 to 1990 significantly reduced revenues to the halibut fleet and precipitated a crisis in the fishery. In 1988 a small group of halibut fishers requested the regulator, the Canadian Department of Fisheries and Oceans (DFO), to introduce individual harvesting rights in the fishery. Following extensive discussions between fishers and a vote in 1990, in which 70 percent of the fishers who responded supported the introduction of individual harvesting rights, the regulator introduced a two year trial program of individual vessel quotas (IVQs) in 1991.

B. The IVQ Fishery

Individual vessel quotas, designated as a percentage of the TAC, were allocated *gratis* to all licence holders and calculated using a formula whereby 30 percent of the initial allocation was based on the length of a vessel and 70 percent on the *best* catch over the previous four years. The allocation formula tended to penalize "highliners" or captains who consistently outperformed the halibut fleet and benefited marginal fishers who may have had just one successful year out of four (Casey et al. 1995). Quotas were not transferable over the trial period except with the corresponding vessel and licence. To ensure exclusivity of the property right, fishers agreed to pay a landing charge to cover the costs of monitoring so as to discourage persons from violating the fishing regulations. In December 1992, at the end of the two year trial period, over 90 percent of all responding halibut quota holders voted to continue with IVQs.

The allocation of individual harvest rights for each vessel eliminated the need for a short fishing season that was previously required to ensure that the TAC was not exceeded. Thus, the introduction of IVQs resulted in an extension of the fishing season from just six days per vessel in 1990 to 214 days in 1991 and 245 days from 1993 onwards. A change in the length of the fishing season, however, did not immediately lead to a dramatic shift as to when or where halibut were caught since much of the harvest was still concentrated over a two month period in 1991. However, as shown in Table 2, by 1996 most of the catch was more or less evenly distributed throughout the entire fishing season.

Since 1993, temporary quota transfers for a fishing season have been permitted. Each vessel's quota is divided in two equal shares and any licensed halibut fisher is allowed to fish a maximum of four shares per vessel (MacGillivray 1996). The limit on the quota shares per vessel means that the maximum harvest of any one vessel is the sum of the four largest shares in the fleet, or 1.57 percent of the TAC. Permanent transfers of quota have been allowed since 1991 but only with the corresponding halibut licence and only to vessels that are not more than 10 feet longer than the vessel which is transferring the licence. Permanent transfers of quota, however, can only be made to vessels *without* an existing halibut licence as only one halibut licence per vessel is permitted.[6] Table 3 provides a record of temporary transfers of quota. Every year since 1993, when temporary transfers were permitted, trading has increased and in 1996 involved 216 vessels and almost half the entire quota (Turris 1997). Most trades have been for quantities of quota ranging from 4,400 to 15,400 pounds and have allowed lower cost fishers to acquire a greater share of the total catch. Despite the change in transferability, under the current TAC, most fishers cannot acquire enough quota to make halibut fishing their sole source of revenue. Thus many halibut licence holders are actively engaged in other fisheries including salmon, rockfish and sablefish (Casey et al. 1995).

The introduction of IVQs has led to a number of important changes in the fishery. Transferability of quota reduced the number of active fishing vessels by almost 20 percent from 1991 to 1993 and by a further 11 percent from 1993 to 1994. Despite the transfers, quota is neither heavily concentrated by area, individuals, or companies, and most of the active vessels remain owner-operated (Porter 1996). Individual harvesting rights have also reduced the number of crew employed from around 1,600 in 1990 to 1,300 in 1992 or a drop of almost 20 percent (MacGillivray 1996). This trend continued after quota transfers were permitted. The fall in crew size is due to a reduction in demand for large crews that were formerly needed to harvest the catch in the "derby" fishery, when the season lasted just a few days and because some individuals are working on more than one vessel due to the longer fishing season.

The major short-run benefit of IVQs has been the increased fishing season which has enabled fishers to sell higher quality and fresher fish and may have also increased the market power of fishers relative to processors for the price they received for halibut (Love et al. 1995). Prior to IVQs, about half the halibut landed was marketed as fresh while today almost the entire catch is sold as higher priced fresh fish (Casey et al. 1995). The price premia, attributable to IVQs, ranged from 22 to 34 percent in the period 1991 to 1994 (Herrmann 1996). These premia suggest that IVQs increased total revenues to the halibut fleet by as much as C$23 million in the first four years of the program. The increased returns far exceed the extra costs associated with IVQ management, which represented in total less than C$3 million for the period 1991-1994.[7] The changes in the fishery have also been accompanied by an increasing price for halibut quota.[8]

In addition to economic changes, IVQs have also led to other benefits in the halibut fishery. In a survey of the fleet in 1994, Casey et al. (1995) found that 72, 73 and 68 percent of respondents either agreed or strongly agreed that IVQs have made fishing safer, resulted in less loss of fishing gear, and reduced wastage of fish. In an earlier survey of the fleet in 1992, fishers rated "Better Safety" as the single most important benefit of IVQs (EB Economics 1992). According to the DFO, discards of undersized halibut have also been reduced by half due to individual harvesting rights (MacGillivray 1996) while incidental catches of other species, such as rockfish, are now landed rather than discarded at sea. A fisher-funded monitoring program also provides greater control over excess and illegal landings and, for the first time, fishers have voluntarily contributed to on-going costs of stock assessment undertaken by the IPHC.

IV. MODELING ECONOMIC EFFICIENCY

To evaluate the changes brought about by private harvesting rights in the BC halibut fishery, we estimate technical, allocative efficiency as well as a measure of overall economic efficiency for each vessel relative to a "best practice" frontier.[9] Technical cost efficiency (TE) measures the ratio of the cost of the technically efficient input bundle to the cost of the actual or observed input bundle;[10] allocative efficiency (AE) measures the firms' choice of the cost-minimizing input proportions relative to input prices;[11] economic efficiency (EE) is the capacity of a firm to produce a given quantity of output at minimum cost (Kopp 1981) and is the product of TE and AE.

We also calculate single-factor cost measures of technical and allocative efficiency in which all other inputs (both variable and fixed) and output are held at observed levels.[12] Each measure of single-factor efficiency reflects the cost reductions possible through the increase of a single factor's efficiency rather than the cost saving associated with a proportional increase in the efficiency of *all* inputs. Further details on measures of efficiency are provided in the Appendix.

A. Data

The data were obtained from DFO cost and earnings surveys from a sample of 97, 163 and 54 halibut fishers in 1988, 1991, and 1994. A selection of 107 observations (1988, 1991 and 1994 combined) was made from the data using the criteria that all vessels used bottom longline gear, caught halibut, and their reported revenues matched (within 10 percent) the independently obtained value of halibut landings recorded for each licence holder.

For each vessel, home port fuel prices were obtained from Chevron Canada and Imperial Oil Canada. The price of labor was measured as an opportunity cost of labor equal to an expected weekly earnings in manufacturing for each region where the vessels have their home ports. Vessel length and quantity and value of fish landings came from records kept by the Government of Canada. A measure of the exploitable biomass (total weight) of the common-pool resource, which indicates the abundance of the halibut stock, came from Sullivan et al. (1994). All economic values are in C$1994 after inflating 1988 and 1991 values by the GDP implicit price index. Summary statistics of the data are presented in Table 4, where the halibut fleet is defined as all longline vessels who had a plurality of revenue from halibut and the general fleet includes all licenced longline vessels which caught halibut.

B. Stochastic Frontier

Halibut fishers combine labor, capital, and fuel to produce an endogenous product, the catch of halibut.[13] Given an exogenous price for landed halibut and expectations about the availability and abundance of halibut, fishers select and transit to halibut grounds and lay their longline gear to maximize expected profits. The halibut longline harvesting technology can be specified as a stochastic frontier.[14] The frontier is stochastic because fishing is sensitive to random factors such as weather, resource availability, and environmental influences (Kirkley et al. 1995). A common specification for the stochastic frontier is the Cobb-Douglas function:[15]

$$\ln H = \alpha_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln F + \alpha_4 \ln B + \epsilon, \qquad (1)$$

where H denotes a vessel's halibut catch in pounds from halibut; K is a vessel's hull length in centimeters and is a measure of the capital stock[16]; L is the flow of labor services for halibut fishing, defined as the number of crew (including the captain) who fished for halibut multiplied by the number of weeks spent halibut fishing; F denotes fuel consumption in liters; and B is the exploitable halibut biomass in ten million pounds. The biomass variable serves as a technological constraint in this stock-flow production technology. Fuel consumption is implicitly defined as the total cost of fuel divided by the price of fuel. The error term ϵ is composed of two independent components and is defined as $\epsilon = V - U$. The V is a two-sided error term which captures random shocks and is assumed to be symmetrical and independently and identically distributed as $N(0,\sigma_V^2)$. The non-negative one-sided error term U captures differences in technical efficiency and is assumed to be distributed half normal (Aigner et al. 1977). Given that we do not have a panel data set[17], technical inefficiency for each vessel is defined as the expected value of U conditional on the value of ϵ, i.e., $E[U|\epsilon]$ (Jondrow et al. 1982).[18]

The vessel or capital is unlikely to be fully variable in any given time period, and hence can be considered as quasi-fixed rather than as a variable input when measuring efficiency. Several factors contribute to this quasi-fixity: one, the vessel is lumpy and difficult to adjust over short time periods; two, halibut fishers use their vessels in other fisheries where DFO imposes restrictions on length and size; and three, persons purchasing halibut quota and a licence cannot use it on a vessel which is more than 10 feet longer than the vessel where it was previously used. Thus, with the exception of the long-run technical primal and cost efficiency measures, all estimates of efficiency are calculated treating the actual vessel length as a quasi-fixed factor.

Short-run efficiency measures can be calculated from the short-run Cobb-Douglas minimum cost frontier, which is self-dual to the short-run Cobb-Douglas stochastic frontier. The short-run frontier is formed by setting K fixed at the observed levels. The efficiency scores fall between zero and one, where a score of one indicates that the fishers are at the best practice frontier.

C. Measuring Efficiency

To evaluate the effects of private harvesting rights upon the different measures of short-run efficiency, efficiency scores were regressed upon dummy variables for year and vessel size class in a second-stage analysis. The explanatory variables were annual dummy variables for 1988(D_{88}) 1991(D_{91}) and 1994 (D_{94}), which were multiplied by dummy variables for two size classes of vessels: small, or less than 50 feet (D_S), and large, equal to or greater than 50 feet (D_L).[19] Tobit regressions account for the censoring of the technical, allocative, and economic efficiency measures at zero and one. The effects of "privatizing the fishery" are evaluated by Wald tests of the null hypothesis of no changes in an efficiency measure between two time periods (1988-1991, 1991-1994, and 1988-1994) and for a given vessel size class (large and small). Thus, $D_{88} D_S - D_{91} D_S = 0$ tests the null hypothesis of equal efficiency for small vessels between 1988 and 1991. If the chi-square value is significant for an efficiency measure (given a single linear restriction and hence one degree of freedom) then the null hypothesis of equal efficiency is rejected.[20]

V. EMPIRICAL RESULTS

The stochastic frontier was estimated by maximum likelihood under the behavioral hypothesis that fishers maximize expected profits (Zellner, Kmenta, and Dreze 1966). Parameter estimates are reported in Table 5 for the 107 observations obtained from the sample data. All parameters are significant at the 5 percent level with the exception of the intercept term. The ratios $\lambda = \sigma_U/\sigma_V$ and $\sigma^2_U/\sigma^2_v+\sigma^2_{u,}$ which ranges between 0 and 1, in Table 5 provide measures of model performance. The ratio λ is greater than one and is statistically significant while the statistically significant ratio $\sigma^2_U/\sigma^2_v+\sigma^2_u$ indicates that $\sigma^2_U \neq 0$ and predominates and that technical inefficiency accounts for more of the variability than random factors. A likelihood ratio test rejects the null hypothesis of a truncated normal in favor of a half-normal.[21]

A. Short-Run Efficiency Measures

The short-run efficiency measures for the general fleet, over all three periods and for all vessels and for small and large vessels, are provided in Table 6. Table 7 indicates no significant differences in the individual efficiency measures between small and large vessels, vessels which received a plurality of their revenues from halibut and those which did not, or between vessels which were in more than one sample period or not. The efficiency scores over all three years indicate substantial scope to improve most measures of efficiency. For all vessels and over all three years, mean short-run allocative efficiency is 0.88, but mean short-run technical cost efficiency is 0.14, giving a low mean short-run economic efficiency of 0.12. Thus given a constant output and fixed capital stock, vessels are allocating variable inputs as a group relatively well at the margin, given their relative factor prices, but are extremely inefficient in terms of technical cost efficiency. The results suggests that improvements in the use of all variable inputs would significantly reduce harvesting costs.

Parameter estimates from the second-stage regressions of short-run efficiency are given in Table 8. All of the coefficients, which are the mean efficiency scores, are significant at the 5 percent level. Table 9 reports the results of the hypothesis tests of no change in the short-run efficiency measures between the three periods for both small and large vessels. The results of the hypothesis tests, whether the efficiency increased or decreased, and whether the change was significant or not, are summarized in Table 10.

The summary results in Table 10 indicate that short-run technical, allocative and economic cost efficiency and the long-run primal measure of technical efficiency declined significantly between 1988 and 1991 for both vessels. All the changes in short-run efficiency for both small and large vessels were positive between 1991 and 1994. The only significant change for large vessels was in terms of economic efficiency, but for small vessels the changes were significant and improved for technical efficiency (long-run primal and short-run cost) and short-run economic efficiency. However, there were no significant changes in short-run technical, allocative or economic efficiency or primal technical efficiency for either vessel class between 1988 and 1994.

B. Single-Factor Efficiency

Single-factor efficiency measures allow us to isolate the most important sources of short-run technical cost and allocative inefficiency. Table 6 indicates that labor use contributes the most to short-run technical cost inefficiency, given a fixed vessel size. The low technical cost inefficiency for labor is explained by the "derby" fishing, practised before the introduction of private harvesting rights in 1991, which placed a premium on the most rapid possible harvesting of fish. Table 10 shows that labor technical cost efficiency significantly fell between 1988 and 1991 for both small and large vessels but significantly increased for small vessels between 1988 and 1991.

A possible explanation for the decline in small vessel labor technical cost efficiency between 1988 and 1991 is that captains failed to adjust crew sizes sufficiently in the first year of IVQs. Fishers may also have been confounded by a close to 50 percent decline in the 1991 total catch relative to 1988, and by severe autumn storms in 1991. The decline might also measure a decrease in efficiency in 1989 and 1990, the two years immediately preceding the introduction of IVQs. The absence of significant gains in labor technical cost efficiency from 1988 to 1994 may be a result of changes in hours worked per day by crew which is not captured in the data. For instance, prior to ITQs in the "derby" fishery, crews often worked 24 hours/day while with the longer fishing season crews may only work as much as 12 hours/day suggests.

Table 6 shows that over all three periods fuel provides the greatest source of single-factor allocative inefficiency. As with the use of labor, under a "derby" fishery vessel owners tried to maximize their harvests in the shortest period of time and paid little heed to conserving fuel or using it in the proportion with labor that would minimize costs. Table 10 indicates that there was a significant and negative change in fuel allocative efficiency from 1988 to 1991 for both small and large vessels but a significant improvement in this efficiency measure for small vessels between 1991 and 1994. There were, however, no significant changes in any of the single-factor efficiency measures for either vessel size class from 1988 to 1994.

The results suggest that even short-run improvements in cost efficiency, due to private harvesting rights, may take several years to materialize and that fishers require some time to adjust their operations to changes in the length of the fishing season and property-rights structure. For example, despite a much longer fishing season with IVQs, in 1991, over 30 percent of the total catch was harvested in just one month, while in 1996 no more than 14 percent of the total catch was caught in any one month. Moreover, with the extended fishing season, time was required for fishers to learn where the fish were located at periods when the halibut fleet had not traditionally been permitted to fish. Further evidence of slow adjustment in fisher behavior is supported by a 1992 survey of halibut fishers in which respondents did not record that the use of fuel changed in 1991 (EB Economics, 1992 p. 14). It may also be true that fishers failed to "fine tune" all facets of their production process in the degree of detail presumed in our model.

C. Producer Surplus

A potential gain from the use of IVQs is an increase in revenues and rents due to an increase in quality and change in product form. One measure of the potential change is the IVQs' unit rent, defined as the output price less the virtual price, the latter which is the marginal opportunity cost of production (Kirkley and Squires 1995). Where fishers are able to adjust their scale of operation at the margin, the unit rent per pound represents the return from owning an additional pound of quota and should approximate its annual lease price. In the BC halibut fishery temporary transfers have only been permitted since 1993. Temporary transfers were only allowed in blocks of quota, usually not less than 4,400 pounds, which equal one-half of the original quota allocation per vessel, while concentration restrictions prevent any one vessel from using more than four blocks of quota. As a result, the average unit rent from the 19 vessels in the sample in 1994 was $3.84/lb, which exceeded the average lease price of quota of $2.00/lb for that year, and which suggests that divisibility and concentration restrictions may have prevented fishers from reaching an optimal scale of operation.[22]

Table 10 summarizes the results in Tables 8 and 9 with respect to changes in unit rents by vessel class and year. Unit rents increased significantly between 1988 and 1991 and again from 1991 to 1994 for both small and large vessels. This indicates that the privatization of the fishery provided immediate gains to fishers in terms of an increase in the returns per pound of fish landed in the first year that IVQs were introduced. Three years after the introduction of IVQs, fishers were able to make further improvements in the quality of their landed product and the price received for halibut which is reflected in additional increases in the unit rents.

Another way to measure changes in the net revenues of fishers is to calculate the producer surplus per vessel and per pound in 1988, 1991 and 1994. Producer surplus is defined as vessel total revenue less observed variable costs, and efficient producer surplus is defined as vessel total revenue less the economically efficient variable costs.[23] Table 10 indicates that for both small and large vessels total observed producer surplus fell significantly between 1988 and 1991 while observed and efficient producer surplus per pound increased significantly over the same period. The apparent contradiction between changes in total and per pound producer surplus is explained by the 44 percent fall in the TAC between 1988 and 1991. From 1991 to 1994 and for the entire period from 1998 to 1994, observed and efficient producer surplus in total and per pound increased significantly for large vessels and on a per pound basis for small vessels.

The changes in unit rents and producer surplus suggest that the principal benefit of IVQs in the halibut fishery has been the increase in total revenue due to higher prices paid for fresher and better quality fish caught and delivered over most of the year.[24] In turn, the improvement in the product form and quality of fish landed is itself directly attributable to IVQs, which have enabled the regulator to increase the length of the fishing season from 14 days in 1988 to 245 days in 1994.

VI. CHARACTERISTICS OF THE PROPERTY RIGHT

The results indicate that fishers still produced below the best practice frontier even after three years of adjustments, despite improvements in several efficiency measures from 1991 to 1994. An explanation for the less-than-expected gains in short-run cost efficiency is that the IVQs specified in the BC halibut fishery lacked important characteristics of a fully specified property right. For instance, restrictions on the transferability and divisibility of quota, compounded by an initial two-year limit on their duration, may have played an important role in limiting improvements in short-run cost efficiency. Further, allowing transfers of quota since 1993 but imposing limits on divisibility may have prevented fishers, especially with smaller vessels, from fully optimizing and reduced the gains in arbitrage efficiency. Limitations on the ability of fishers to adjust vessel size to its optimal level may also explain why three years after privatization of the resource many fishers remained below the best practice frontier. For instance, most of the halibut fleet participate in other fisheries (such as salmon) which are regulated by vessel licences, input controls and limits on vessel size. In addition, fishing licences are "bundled" by vessel, so that fishers wishing to increase the size of their vessel must find a willing seller who has the same combination of licences and who owns a larger vessel. Finding the desired match of buyer and seller is difficult and costly, and may even be impossible, depending upon the combination of fishing licences and vessel size desired. This bundling of licences and vessels increases transactions costs and ensures that most halibut fishers, who wish to continue participating in other fisheries, are unable to adjust their vessels to the optimal size.

Whatever the deficiencies in the property right, part of the explanation for relatively modest gains in short-run cost efficiency may be that fishers require several years to optimize their operations. For example, the period spent fishing changed considerably between 1991 and 1994 and yet again between 1994 and 1996 while the number of active vessels declined by 28 percent between 1991 and 1994 and again by 10 percent between 1994 and 1996. Similarly, both the number of temporary transfers of quota and the number of vessels involved in quota trading more than doubled between 1993 and 1996. This suggests that several fishing seasons may be necessary for fishers to trade quota to reach a desired scale of operation. Even if the property rights are not bundled or attenuated, gains in efficiency from harvesting with an optimal sized vessel cannot arise until the existing vessel is replaced---a period of time which may be several years. These long-run gains in efficiency may be very large. For instance, Table 6 indicates that the average long-run technical cost efficiency score for all vessels would increase five-fold from 0.14 to 0.70 if fishers were able to freely adjust their vessel size.[25]

To quantify some of the potential losses associated with limitations in the property rights, the total rents in the fishery were calculated in 1991, with and without restrictions on transfers of quota, using the General Algebraic Modelling System (GAMS) (Brooke et al. 1996).[26] The results indicate that if IVQs had been transferable in 1991 the producer surplus would have been 4.12 percent higher. The relatively small gains from allowing transfers is explained by the very little difference in the virtual prices of the 44 vessels in the 1991 sample. Despite the small change in producer surplus, the model indicates that transferability of the property right would have resulted in a very different outcome in terms of the distribution of the harvest among fishers.[27]

VII. CONCLUDING REMARKS

The "privatizing" of the BC halibut fishery is a natural experiment of the effects of changes in property rights in a common-pool resource. The introduction of private harvesting rights in 1991 led to an important transformation in the industry and the behavior of fishers. In particular, the creation of an exclusive harvesting right allowed for an increase in the fishing season from just six days in 1990 to over six months in 1991 and over eight months since 1992. A longer fishing season, in turn, allowed fishers to harvest their catches over a greater period of time, to increase the quality and improve the product form of the landed product from frozen to fresh fish and to receive a higher price for halibut. As a result, unit rents and producer surplus per pound significantly increased between 1988 and 1991 and between 1991 and 1994. Surveys of fishers also indicate that private harvesting rights made fishing safer, reduced losses of fishing gear, and decreased wastage of fish. Further, a shift in the property-right regime led to greater cooperation or co-management between the fishers and the regulator. Such improvements would not have been possible under the previous property-rights structure where fishers tried to catch as many fish as possible in a very limited period of time.

Despite the gains in safety and net revenues from privatization, an analysis of changes in the fishery reveals that most short-run cost efficiency measures were less in 1991 than in 1988. Over the 1991-1994 period, however, small vessels significantly improved their short-run technical, labour technical, and fuel allocative cost efficiency while large vessels realized significant improvements in short-run cost economic efficiency. By contrast, the observed producer surplus per pound for small and large vessels rose 52 and 89 percent between 1988 and 1991 and for both vessel classes by 25 percent between 1991 and 1994.

The results suggest that ensuring an exclusive property right with a good quality of title is sufficient to yield substantial gains in revenues and producer surplus. Nevertheless, total producer surplus would have been even higher without restrictions on transferability. Further, without the ability to freely trade the property right (in divisible units) or to aggregate quota because of concentration restrictions, firms were prevented from optimizing at the margin. Transactions costs, the bundling of property rights and uncertainty about the duration of the right may also have delayed or even prevented gains in technical and allocative efficiency.

The study provides a number of insights to regulators of common-pool resources. First, the greatest short-run gains from privatization may occur more on the output side, in terms of revenue and product form, rather than in terms of costs and the mix of inputs. Second, the potential costs in terms of long-run technical efficiency from the bundling of property rights and other restrictions suggest that regulators should consider the impact of pre-existing regulations and institutional structures (for example, rate-of-return regulations for coal-fired electric utilities) when devising changes in property rights (such as the introduction of tradeable discharge sulfur dioxide permits). Such considerations are especially important in industries where firms produce a range of outputs each of which may be separately regulated. Third, even accounting for deficiencies in the property right, changes in short-run cost efficiency may not be instantaneous and may involve a period of adjustment and learning by firms. Finally, only by paying careful attention to *all* the characteristics of the property right and their interactions, the pre-existing regulations, and the constraints faced by firms will regulators realize the full benefits of “privatizing the commons”.

APPENDIX

Economic efficiency is computed as the ratio of the minimum cost input bundle to the cost of the actual or observed input bundle. EE equals the product of TE and AE. AE can be calculated as the ratio of EE to TE, i.e., AE = EE/TE, which gives the increase in cost from such inefficiency. The indexes for technical cost, allocative, and economic efficiency are bounded between zero and one and indicate the cost savings made possible through the elimination of input inefficiency. That is, the values 1-TE, 1-AE, and 1-EE indicate the reduction in total cost if the inefficiency associated with technical cost, allocative, and overall economic efficiency is eliminated.

The measures of TE, AE and EE are obtained by first deriving the stochastic frontier and then calculating their values in terms of cost. The stochastic frontier is obtained under the assumption of expected profit maximization (Zellner, Kmenta, and Dreze 1966) which allows for endogenous output. Measures of technical cost, allocative, and overall minimum cost efficiency are derived from Kopp's (1981) extension of Farrell (1957), who decomposed deviations from a nonhomothetic deterministic frontier production function into measures of technical cost, allocative, and economic efficiency. Kopp and Diewert (1982) extended Kopp's (1981) approach from the primal production function to the frontier minimum cost function, which can include flexible functional forms. Shephard's Lemma is used to obtain the economically efficient factor demands for a given output level, from which the economically efficient minimum cost function can be constructed. Technically efficient factor demands can be solved from the technically efficient minimum cost function by the approach of Kopp and Diewert (1982). Specific applications and formulae for the Cobb-Douglas functional form are also provided by Bravo-Ureta and Rieger (1991) and Taylor, Drummond, and Gomes (1986).

A deterministic frontier supposes that deviations from "best-practice" are entirely due to inefficiency rather than any stochastic factors, such as poor weather, natural fluctuations in resource stocks, random variations in machinery performance or breakdowns, and luck. Given the inherent randomness in harvesting a natural resource in a stock-flow production technology, the stochastic is preferred over a deterministic frontier (Kirkley et al. 1995). Bravo-Ureta and Rieger (1991) extended the deterministic decomposition technique of Kopp (1981) and Kopp and Diewert (1982) to stochastic formulations that yield technical cost, allocative, and economic efficiency measures that adjust the firm's observed output for random disturbances. Following Bravo-Ureta and Rieger (1991) and Greene (1993, page 94), the random noise is eliminated from the efficiency measures by purging the observed output measured by the random disturbance V. In this case, the estimate of V from Eq. (1) is subtracted from observed output where if Y is output then $Y-Y^{\wedge} = V-U$ which implies $Y-Y^{\wedge}+U = V$ such that $Y-V = Y-(Y-Y^{\wedge}+U) = Y-Y+Y^{\wedge}-U = Y^{\wedge}-U$ (Schmidt 1985).

The technical efficiency index (bounded between zero and one) is an input-oriented measure calculated from the self-dual Cobb-Douglas minimum cost function which is the ratio of the best practice input usage to actual usage, output held constant. Allocative efficiency involves the selection of an input mix that allocates factors to their highest valued uses and thus introduces the opportunity cost of inputs to the measurement of efficiency. Single-factor technical efficiency indexes establish the minimum possible bounds on individual input utilization.

Multi-factor allocative efficiency indexes represents the reduction in production costs that would occur if production were both technically and allocatively efficient rather than technically efficient but allocatively inefficient. It compares the cost of producing the technically efficient input set, given relative factor prices (thereby giving the minimum cost input ratio or factor proportions), to the cost of producing the technically efficient input set given the observed input ratio (which gives the cost inefficient input ratio or factor proportions). The single-factor allocative efficiency measure has the same cost interpretation as the multi-factor allocative measure (Kopp 1991, p. 494). The single-factor allocative efficiency measure compares the cost of producing the technically efficient input set, given relative factor prices (thereby giving the minimum cost input ratio or factor proportions), to the cost of producing the single-factor technically efficient input set (defined by holding all inputs but the one in question at their observed level and where the input in question is at the minimum input quantity feasible), given the observed input ratio (thereby giving the cost inefficient input ratio or factor proportions). Single-factor allocative efficiency can also be measured as the ratio of the overall efficient (minimum cost) cost to the cost of the single-factor technically efficient input vector. In short, the single-factor allocative efficiency measure evaluates the cost of producing the single-factor technically efficient input set with the observed rather than optimal input proportions.

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TABLE 1
Season Length, Number of Active Fishing Vessels and Total Catch in the BC Halibut Fishery

Year	Season Length (days)	Number of Active Vessels	Total Catch (pounds)
1980	65	333	5,650,447
1981	58	337	5,654,856
1982	61	301	5,524,783
1983	24	305	5,416,757
1984	22	334	8,276,152
1985	22	363	9,587,902
1986	15	417	10,240,471
1987	16	424	12,251,086
1988	14	435	12,859,562
1989	11	435	10,738,715
1990	6	435	8,569,367
1991	214	433	7,189,273
1992	240	431	7,630,198
1993	245	351	10,560,141
1994	245	313	9,900,958
1995	245	294	9,499,717
1996	245	281	9,499,717

Sources: Porter (1996), MacGillivray (1996), Turris (1997), Herrmann (1996)

TABLE 2
Percentage of Total Halibut Catch Caught each Month, 1991, 1994 and 1996

1991											
Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
NA	NA	NA	NA	17%	31%	7%	8%	10%	26%	NA	NA
1994											
Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
NA	NA	24%	17%	17%	6%	11%	5%	6%	14%	NA	NA
1996											
Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
NA	NA	14%	14%	13%	12%	11%	12%	11%	11%	NA	NA

Source: Turris (1997)

Notes:
1. The fleet is allowed to land halibut in the first few days in November and thus the harvest for November is added to October.
2. NA refers to months outside of the fishing season.
3. The monthly catch percentages do not sum to 100 due to rounding error.

TABLE 3
Temporary Transfers of Individual Quota in the BC Halibut Fishery

Year	No. of Transfers	No. of Vessels Involved	% of Total Quota
1991	0	0	0
1992	0	0	0
1993	178	94	19
1994	306	154	34
1995	360	184	39
1996	413	216	44

Source: Turris (1997)

TABLE 4
Summary Statistics of the Data

Variable	Halibut Fleet Mean	Halibut Fleet St. Dev.	General Fleet Mean	General Fleet St. Dev.
1988, 1991 and 1994 Halibut Data:				
Vessel length	12.65	2.78	14.10	5.45
Crew-weeks	10.08	6.70	12.91	9.68
Fuel quantity	4955.01	5212.75	6995.15	9505.11
Halibut revenue	66104.92	50084.16	88747.81	70140.23
Price of halibut	2.81	0.60	2.78	0.72
Halibut landings	25090.42	20132.90	34026.63	28966.98
Crew	3.25	1.32	3.78	1.48
Weeks fished	3.11	1.65	3.36	1.92
Landings/crew	7245.96	4312.38	8143.52	4561.69
Landings/week	8995.51	7704.21	11731.65	9798.18
Fuel cost	1616.09	1740.24	2420.62	3634.45
Labor cost	1816.83	655.43	2081.87	740.22
No. observations	36		107	
1988 Halibut Data:				
Vessel length	14.01	2.79	14.48	3.54
Crew-weeks	13.64	6.31	15.68	11.33
Fuel quantity	4951.96	3682.49	8303.38	13201.26
Revenue	91397.09	55032.15	107329.48	74208.75
Price	2.03	0.14	2.03	0.15
Landings	44506.27	24560.20	51769.55	33978.76
Crew	4.09	1.25	4.52	1.55
Weeks fished	3.36	1.29	3.39	1.97
Landings/crew	10880.00	4088.18	10735.89	4863.64
Landings/week	15489.24	10148.10	17541.05	11388.93
Fuel cost	1954.27	1086.63	3257.05	5137.61
Labor cost	2131.14	714.44	2346.55	767.18
No. observations	11		44	

1991 Halibut Data:

Vessel length	12.04	2.59	13.44	7.34
Crew-weeks	7.86	5.10	8.57	5.39
Fuel quantity	3609.77	2545.11	4153.69	2767.51
Revenue	42170.29	29688.79	51378.07	34241.58
Price	3.04	0.23	3.08	0.21
Landings	13576.86	8901.37	16475.10	10690.77
Crew	2.90	1.18	3.02	1.09
Weeks fished	2.71	1.65	2.91	1.79
Landings/crew	4563.57	1580.80	5224.56	1972.49
Landings/week	5894.90	4645.41	7199.40	5809.97
Fuel cost	998.21	725.82	1122.86	710.79
Labor cost	1681.71	637.43	1745.87	590.17
No. observations	21		44	

1994 Halibut Data:

Vessel length	12.13	1.63	14.73	3.77
Crew-weeks	12.00	2.45	16.53	9.85
Fuel quantity	12025.94	8699.39	10545.78	7758.94
Revenue	122208.25	67848.68	132257.05	82213.02
Price	3.72	0.29	3.85	0.30
Landings	32413.00	17014.47	33583.47	19681.81
Crew	2.75	1.27	3.79	1.28
Weeks fished	4.50	2.15	4.37	1.74
Landings/crew	11334.92	4133.23	8682.33	4283.86
Landings/week	7416.02	4143.12	8653.84	6131.51
Fuel cost	3930.00	4201.54	3488.95	2548.30
Labor cost	1660.80	282.30	2247.05	715.96
No. observations	4		19	

Notes:
1. All values are in C$1994 and are per vessel.
2. Crew size includes captain.
3. Weeks fished pertain to weeks actively fishing halibut.
4. Halibut landings are in pounds and the price is per pound.
5. Fuel quantity is in liters and vessel length in metres.
6. Halibut fleet is defined as longline vessels which had a plurality of revenue from halibut.

TABLE 5
Parameter Estimates of the Stochastic Production Frontier

Variable	
Constant	2.2436
	(1.4287)
Vessel length	1.0294*
	(0.2221)
Labor	0.4122*
	(0.1175)
Fuel	0.2769*
	(0.0781)
Biomass	1.0281*
	(0.3508)
Log-likelihood	-90.7885
No. Observations	107
σ_V	0.10056
σ_U	0.65863
σ_U/σ_V	2.5593*
	(1.2394)
$\sigma_V+\sigma_U$	0.8713*
	(0.1080)
$\sigma^2_V+\sigma^2_u$	0.7592*
	(0.2441)
$\sigma^2_U/(\sigma^2_V+\sigma^2_U)$	0.8675*
	(0.1464)

Notes: 1. Dependent variable is halibut catch in pounds.
2. Vessel length is in metres, fuel is in hundreds of litres and biomass is in ten million pounds.
3. Standard errors in parentheses.
4. * indicates statistically significant at 5 percent level.
5. The model was estimated under the assumption that the technical inefficiency error term (U) is distributed half-normal.
6. A likelihood ratio (LR) test was performed to test the null hypothesis of a one-sided error term by the ratio $\sigma^2_U/(\sigma^2_V+\sigma^2_U)$. Using the critical value in Table 1 of Kodde and Palm (1986) and the calculated LR of 3.555, the null hypothesis could not be rejected at the 5% level of significance.

TABLE 6
Overall Efficiency Scores and Producer Surplus Measures for 1988, 1991, 1994

Efficiency Scores	Mean	St. Dev.	min	max.
Tech. efficiency (primal)	0.56	0.19	0.07	0.87
Long-run tech. cost efficiency	0.70	0.15	0.22	0.92
Short-run tech. cost efficiency	0.14	0.10	0.01	0.47
Short-run economic efficiency	0.12	0.09	0.01	0.42
Short-run allocative efficiency	0.88	0.10	0.46	0.99
Fuel technical efficiency	0.78	0.12	0.31	0.97
Labor technical efficiency	0.26	0.13	0.03	0.76
Fuel allocative efficiency	0.17	0.14	0.01	0.75
Labor allocative efficiency	0.46	0.27	0.05	0.99
Producer Surplus Measures	**Mean**	**St. Dev.**	**min**	**max.**
Producer surplus	79,206	65,723	-25,179	305,999
Producer surplus (efficient)	87,595	69,089	11,865	343,221
Producer surplus/pound	2.35	0.98	-5.00	4.31
Producer surplus (efficient)/pound	2.75	0.72	1.73	4.46

Notes: 1. Number of observations equals 107.
2. Producer surplus measured in Canadian 1994 dollars.

TABLE 7

Tests of Significance whether Vessels are Identical in Every Period

Efficiency	H_0 : Small vessels = Large vessels			H_0 : Halibut fleet = General fleet		
	χ^2	Significance	Reject (Y/N)	χ^2	Significance	Reject (Y/N)
Technical Efficiency (primal)	0.32	0.95594	N	2.24	0.52465	N
Long-Run Technical Efficiency (cost)	0.39	0.94139	N	1.93	0.58697	N
Short-Run Technical Efficiency (cost)	0.71	0.87161	N	4.91	0.17849	N
Short-Run Economic Efficiency	0.16	0.98376	N	4.21	0.24012	N
Short-Run Allocative Efficiency	1.17	0.76082	N	1.05	0.78798	N
Single-Factor Fuel Technical Efficiency	0.76	0.85991	N	1.45	0.69410	N
Single-Factor Labor Technical Efficiency	0.22	0.97433	N	2.66	0.44755	N
Single-Factor Fuel Allocative Efficiency Single-	0.20	0.97695	N	3.26	0.35318	N
Factor Labor Allocative Efficiency	1.05	0.78841	N	3.35	0.34053	N
Unit Rent	20.96	0.00011	Y	4.04	0.25758	N
Observed Producer Surplus	47.18	0	Y	1.95	0.58375	N
Efficient Producer Surplus	50.36	0	Y	3.83	0.28099	N
Observed Producer Surplus per pound	3.66	0.29995	N	1.07	0.78471	N
Efficient Producer Surplus per pound	20.00	0.00017	Y	0.84	0.83990	N

Notes: 1. Hypothesis tests are all Wald tests with three degrees of freedom and 5% level of significance.
2. Small vessels are boats less than 50 feet and large vessels are equal to or greater than 50 feet in length.
3. Halibut vessels are boats which receive a plurality of revenue from halibut while general vessels receive less than 50 percent of their total revenue from halibut.

TABLE 7 (continued...)

Tests of Significance whether Vessels are Identical in Every Period

Efficiency	H_0 : Core vessels = Non-core vessels		
	χ^2	Significance	Reject (Y/N)
Technical Efficiency (primal)	1.07	0.78471	N
Long-Run Technical Efficiency (cost)	0.84	0.83990	N
Short-Run Technical Efficiency (cost)	1.75	0.62639	N
Short-Run Economic Efficiency	1.32	0.72395	N
Short-Run Allocative Efficiency	4.87	0.18152	N
Single-Factor Fuel Technical Efficiency	2.44	0.48611	N
Single-Factor Labor Technical Efficiency	2.70	0.43975	N
Single-Factor Fuel Allocative Efficiency Single-	1.59	0.66128	N
Factor Labor Allocative Efficiency	1.03	0.79386	N
Unit Rent	6.69	0.08251	N
Observed Producer Surplus	1.85	0.60502	N
Efficient Producer Surplus	1.81	0.61201	N
Observed Producer Surplus per pound	1.03	0.79306	N
Efficient Producer surplus per pound	6.69	0.08242	N

Notes: 1. Hypothesis tests are all Wald tests with three degrees of freedom at 5% level of significance.
2. Core vessels are boats for which data is available in two out of the three sample periods. Non-core vessels are boats for which data is available in only one of the three sample periods.

TABLE 8

Second-Stage Regression Results

VARIABLE	TE (primal)	LR Cost TE	SR Cost TE	SR Cost AE	SR Cost EE	Unit Rent
88 - Small	0.663** (0.033)	0.779** (0.026)	0.201** (0.018)	0.880** (0.020)	0.174** (0.016)	1.926** (0.039)
88 - Large	0.638** (0.038)	0.757** (0.030)	0.180** (0.020)	0.907** (0.023)	0.166** (0.018)	2.061** (0.044)
91 - Small	0.449** (0.028)	0.619** (0.023)	0.076** (0.015)	0.853** (0.017)	0.065** (0.013)	3.014** (0.033)
91 - Large	0.466** (0.052)	0.632** (0.041)	0.080** (0.028)	0.867** (0.031)	0.067** (0.025)	3.172** (0.061)
94 - Small	0.601** (0.048)	0.737** (0.038)	0.151** (0.026)	0.889** (0.029)	0.134** (0.022)	3.667** (0.056)
94 - Large	0.600** (0.062)	0.738** (0.050)	0.136** (0.033)	0.912** (0.038)	0.128** (0.030)	3.967** (0.073)
Log-Likelihood	40.7976	65.4919	107.6291	95.161	121.5803	R^2=0.9304 26.952

Notes: 1. All variables are dummy variables.
2. All measures of efficiency are from a Tobit model censored at 0 and 1 except for short-run scale efficiency which is estimated with ordinary least squares.
3. Standard errors are in parentheses.
4. * (**) indicates statistically significant at 5% (1%).
5. Parameter estimates give mean efficiency scores.
6. TE=technical efficiency, EE=economic efficiency, AE=allocative efficiency, LR=long run, SR= short run.
7. Unit rent is defined as output price less a linear approximation of the virtual price.

TABLE 8 (contd....)

Second-Stage Regression Results

VARIABLE	Single-Factor TE		Single-Factor AE	
	FUEL	LABOR	FUEL	LABOR
88 - Small	0.768** (0.023)	0.301** (0.023)	0.243** (0.024)	0.597** (0.049)
88 - Large	0.743** (0.026)	0.315** (0.026)	0.227** (0.027)	0.524** (0.056)
91 - Small	0.809** (0.020)	0.204** (0.020)	0.083** (0.020)	0.350** (0.042)
91 - Large	0.803** (0.036)	0.211** (0.036)	0.084* (0.037)	0.367** (0.078)
94 - Small	0.753** (0.033)	0.292** (0.033)	0.189** (0.034)	0.464** (0.071)
94 - Large	0.728** (0.043)	0.303** (0.043)	0.192** (0.045)	0.431** (0.093)
Log-Likelihood	80.2342	79.5586	76.99865	-1.6216

Notes: 1. TE=technical efficiency and AE= allocative efficiency.
2. * (**) indicates statistically significant at 5% (1%).

TABLE 8 (contd....)

Second-Stage Regression Results

VARIABLE	Observed Producer Surplus	Efficient Producer Surplus	Observed Producer Surplus per lb	Efficient Producer Surplus per lb
88 - Small	69,476** (9,924.9)	77,139** (10,254)	1.686** (0.146)	1.942** (0.039)
88 - Large	130,770** (11,385)	143,021** (11,762)	1.533** (0.168)	2.072** (0.046)
91 - Small	32,476** (8,510.6)	37,681** (8,792.3)	2.556** (0.126)	3.024** (0.033)
91 - Large	88,893** (15,693)	96,476** (16,212)	2.897** (0.231)	3.180** (0.061)
94 - Small	79,385** (14,325)	88,080** (14,800)	3.202** (0.211)	3.691** (0.056)
94 - Large	186,820** (18,756)	203,422** (19,377)	3.627** (0.276)	3.985** (0.073)
R-Squared	0.4568	0.4753	0.4726	0.930

Notes: 1. * (**) indicates statistically significant at 5% (1%).

TABLE 9

Tests of Significance for Changes in Efficiency and Producer Surplus by Vessel Size Class

Efficiency	H_0 : 1988 (small) = 1991 (small)			H_0 : 1988 (large) = 1991 (large)		
	χ^2	Significance	Reject (Y/N)	χ^2	Significance.e	Reject (Y/N)
Technical Efficiency (primal)	24.14	0	Y	7.14	0.00753	Y
Long-Run Technical Efficiency (cost)	21.37	0	Y	5.88	0.01527	Y
Short-Run Technical Efficiency (cost)	28.43	0	Y	8.44	0.00366	Y
Short-Run Economic Efficiency	28.36	0	Y	10.47	0.0121	Y
Short-Run Allocative Efficiency	1.12	0.29070	N	1.05	0.30578	N
Single-Factor Fuel Technical Efficiency	1.90	0.16848	N	1.81	0.17885	N
Single-Factor Labor Technical Efficiency	10.25	0.00137	Y	5.30	0.2137	Y
Single-Factor Fuel Allocative Efficiency Single-	26.27	0	Y	9.59	0.00195	Y
Factor Labor Allocative Efficiency	14.56	0.00014	Y	2.69	0.10093	N
Unit Rent	454.99	0	Y	215.93	0	Y
Observed Producer Surplus	8.01	0.00466	Y	4.67	0.03077	Y
Efficient Producer Surplus	8.54	0.00349	Y	5.34	0.02014	Y
Observed Producer Surplus per pound	20.44	0.00001	Y	22.89	0	Y
Efficient Producer Surplus per pound	448.18	0	Y	213.65	0	Y

Notes: 1. Hypothesis tests are all Wald tests with one degree of freedom.

TABLE 9 (continued....)

Tests of Significance for Changes in Efficiency and Producer Surplus by Vessel Size Class

Efficiency	H_0 : 1991 (small) = 1994 (small)			H_0 : 1991 (large) = 1994 (large)		
	χ^2	Significance	Reject (Y/N)	χ^2	Significance	Reject (Y/N)
Technical Efficiency (primal)	7.5	0.00618	Y	2.73	0.28553	N
Long-Run Technical Efficiency (cost)	7.12	000762	Y	2.69	0.10075	Y
Short-Run Technical Efficiency (cost)	6.32	0.01197	Y	1.69	0.19402	N
Short-Run Economic Efficiency	2.53	0.11201	N	6.90	0.00861	Y
Short-Run Allocative Efficiency	1.16	0.28102	N	0.85	0.35743	N
Single-Factor Fuel Technical Efficiency	2.13	0.14463	N	1.81	0.17885	N
Single-Factor Labor Technical Efficiency	5.17	0.02292	Y	2.65	0.10326	N
Single-Factor Fuel Allocative Efficiency Single-	7.06	0.00787	Y	3.49	0.06187	N
Factor Labor Allocative Efficiency	1.92	0.16635	N	0.28	0.59401	N
Unit Rent	101.00	0	Y	69.37	0	Y
Observed Producer Surplus	7.93	0.00488	Y	16.04	0.00006	Y
Efficient Producer Surplus	8.57	0.00341	Y	17.92	0.00002	Y
Observed Producer Surplus per pound	6.94	0.00844	Y	4.12	0.04247	Y
Efficient Producer Surplus per pound	104.96	0	Y	70.94	0	Y

Notes: 1. Hypothesis tests are all Wald tests with one degree of freedom.

TABLE 9 (continued....)

Tests of Significance for Changes in Efficiency and Producer Surplus by Vessel Size Class

Efficiency	H_0 : 1988 (small) = 1994 (small)			H_0 : 1988 (large) = 1994 (large)		
	χ^2	Significance	Reject (Y/N)	χ^2	Significance	Reject (Y/N)
Technical Efficiency (primal)	1.14	0.28553	N	0.27	0.60266	N
Long-Run Technical Efficiency (cost)	0.84	0.35936	N	0.10	0.75340	N
Short-Run Technical Efficiency (cost)	2.55	0.11023	N	1.25	0.26266	N
Short-Run Economic Efficiency	1.18	0.27650	N	2.20	0.13803	N
Short-Run Allocative Efficiency	0.01	0.90384	N	0.06	0.81183	N
Single-Factor Fuel Technical Efficiency	0.13	0.71760	N	0.10	0.75618	N
Single-Factor Labor Technical Efficiency	0.05	0.82042	N	0.05	0.82772	N
Single-Factor Fuel Allocative Efficiency Single-	1.70	0.19220	N	0.43	0.51221	N
Factor Labor Allocative Efficiency	2.37	0.12381	N	0.73	0.39236	N
Unit Rent	655.92	0	Y	495.85	0	Y
Observed Producer Surplus	0.32	0.56967	N	6.53	0.01063	Y
Efficient Producer Surplus	0.37	0.54340	N	7.10	0.00771	Y
Observed Producer Surplus per pound	34.93	0	Y	42.06	0	Y
Efficient Producer Surplus per pound	659.32	0	Y	497.43	0	Y

Notes: 1. Hypothesis tests are all Wald tests with one degree of freedom.

TABLE 10

Direction and Significance of Efficiency Changes Over Time by Vessel Size Class: General Fleet

Efficiency	Small Vessels			Large Vessels		
	1988-91	1991-94	1988-94	1988-91	1991-94	1988-94
Technical Efficiency (primal)	-*	+*	-	-*	+	-
Long-Run Technical Efficiency (cost)	-*	+*	-	-*	+	-
Short-Run Technical Efficiency (cost)	-*	+*	-	-*	+	-
Short-Run Economic Efficiency	-*	+	-	-*	+*	-
Short-Run Allocative Efficiency	-	+	+	-	+	+
Single-Factor Fuel Technical Efficiency	+	-	-	+	-	-
Single-Factor Labor Technical Efficiency	-*	+*	-	-*	+	-
Single-Factor Fuel Allocative Efficiency Single-	-*	+*	-	-*	+	-
Factor Labor Allocative Efficiency	-*	+	-	-	+	-
Unit Rent	+*	+*	+*	+*	+*	+*
Observed Producer Surplus	-*	+*	+	-*	+*	+*
Efficient Producer Surplus	-*	+*	+	-*	+*	+*
Observed Producer Surplus per pound	+*	+*	+*	+*	+*	+*
Efficient producer surplus per pound	+*	+*	+*	+*	+*	+*

Notes: 1. * indicates statistically significant at 5% level.
2. + (-) indicates positive (negative) change in efficiency measure.

FOOTNOTES

1. The first empirical study that tests for changes in efficiency in a common-pool resource, following a change in the property right, is Grafton et al. (1995).

2. Cheung (1970, page 69) observed almost 30 years ago that, “To evaluate economic efficiency by comparing imaginary contracts and regulations is futile...”

3. These characteristics have been described by various authors including Scott and Johnson (1985), Posner (1989) and Devlin and Grafton (1998).

4. Past fisheries regulations have tried to solve the problems associated with the exploitation of common-pool resources by imposing controls over access and limits on the type and quantity of inputs which fishers can use. This may be called restricted open access. In some cases, restrictions also include limitations on the number of vessels and may be called regulated restricted access (Homans and Wilen 1997). Such restrictions fall short of creating a property right over harvest right and in many cases have failed to address the externalities prevalent in fisheries (Townsend 1990).

5. In 1990, fishers were able to harvest halibut in two out of three designated “openings”. Each vessel could only fish a total of six days despite the fact that the fishing season was officially 10 days long.

6. Turris (1997) estimates that since 1991 there have been not less than 50 and not more than 100 permanent transfers of quota with a halibut licence.

7. Extra costs associated with IVQs, funded directly by fishers, amounted to about C$800,000 in 1993/94 (MacGillivray 1996).

8. The prices for permanent trades of quota per pound for the years 1991 to 1994 were C$1.33, C$1.96, C$2.47, and C$3.08 (Porter 1996). The average lease price of quota per pound, after temporary transfers were permitted in 1993, was C$1.65 in 1993 and C$2.00 in 1994 (Turris 1997).

9. This discussion draws upon Bravo-Ureta and Rieger (1991), Farrell (1957), Kopp (1981), Kopp and Diewert (1982) and Greene (1993). The approach is that of input-based Farrell efficiency measures. Farrell efficiency measures are defined by comparing input bundles along a given ray through the origin. This ray is defined by the observed input proportions. Although these radial measures were originally considered only for the unit isoquant of a linear homogenous technology, Kopp (1981) generalized them to nonhomothetic technologies.

10. Technical efficiency is more precisely called technical cost efficiency. It is an input-oriented measure, rather than that directly measured from the estimated best-practice production frontier, an output-oriented measure. The input and output-oriented measures are equivalent given

constant returns to scale. The technical inefficiency term from the stochastic production frontier is adapted for cost efficiency by dividing by the production frontier's degree of economies of scale (Schmidt and Lovell 1979, Greene 1993, page 89).

11. A production process is allocatively efficient in its input usage when it equates ratios of marginal products with the input price ratios, when the objective is to minimize cost given output and input prices.

12. The single-factor technical cost efficiency measures are calculated from the isocost line associated with the minimum input quantity of each input, given fixed capital and the other variable factor fixed at observed levels, following Kopp (1981, page 492). The technically cost efficient input, with other inputs held at their observed levels, was calculated from the corresponding isoquant. They could be equivalently calculated in the same manner as the technically cost efficient inputs for the multiple-factor technical cost efficiency measures, adapting Kopp and Diewert (1982) and Taylor et al. (1986, pages 114-115) and Greene (1993, pages 89-94). As noted by Kopp (1981, page 493), the single-factor technical cost efficiency measure is functionally related to relative factor prices and thus not entirely free of allocative effects. The single-factor allocative efficiency measures are calculated following Kopp (1981, page 494).

13. Fishers, both before and after the introduction, were able to choose their expected harvest of halibut. In the derby fishery, immediately prior to 1991, fishers worked as much as 24 hours a day to catch as many fish as possible in the limited fishing season. Since 1993, fishers have been able to trade quota shares to increase or decrease their scale of operations. In 1991 and 1992, when only transfers of halibut licences (with attached quota) were allowed, fishers still had the flexibility to land up to 10 percent less or more than their quota which could be banked or deducted from their quota holdings in the following year. In addition, fishers by their choice of where and when to fish can adjust their output mix in terms of the quality and size of fish harvested.

14. The stochastic frontier framework was introduced by Aigner et al (1977). Their model was extended by Schmidt and Lovell (1979) to incorporate allocative inefficiency.

15. The Cobb-Douglas functional form was selected because it is self-dual, i.e., the cost function can be directly obtained from the production function and vice versa. Flexible functional forms are, in general, not self-dual. Self-duality is a necessary property to derive the measures of allocative and overall efficiency from the production frontier (primal), in which there is an internally consistent and exact relationship between the allocative inefficiency in factor demands and in the associated cost function. Measuring allocative inefficiency from a (minimum) cost function, whether a self-dual or flexible functional form, presupposes an exogenous output and cost minimization. By contrast, the production frontier (primal) presupposes endogenous output and we consider the behavioral objective of expected profit maximization. Kumbhakar (1997) recently modeled an exact relationship for allocative efficiency. Following Schmidt and Lovell (1979), he derived the exact relationship between allocative inefficiency in the share equations (factor demand equations) and in the cost function for a translog functional form. This approach

also presupposes that we have cost minimization given an exogenous output. The Cobb-Douglas minimum cost function and factor demand are given in Eqs. (3)-(4) of Schmidt and Lovell (1979) and Eq. (2) of Taylor et al. (1986).

16. We specify capital as a stock and assume that its services are proportional because capital is constrained over the short-run and we wish to derive short-run cost efficiency measures.

17. When data are in a series of independent cross-sections, rather than as panel data, Deaton (1985) suggests the tracking of “cohorts”---a group with a fixed membership whose individual members can be identified over time--- instead of individuals. Such an approach cannot be incorporated directly into the estimation of the stochastic production frontier. However, our second-stage regressions of the different efficiency measures adopts this suggestion where we evaluate efficiency over time for small and large vessels (cohorts).

18. Alternatively technical efficiency may be defined as 1 - technical inefficiency. Whether technical inefficiency is assumed to be unexpected and unknown, or expected and foreseen, when the firm chooses its inputs affects the specification and estimation of the production function (Kumbhakar 1987). Given the overwhelming importance of “captain's skill” in locating and catching fish and the inherent stochastic effects from weather, temperature, and biological variations in fishing, it is likely that technical inefficiency is more unforseen than expected. Thus we specify the technical inefficiency as unexpected or unforseen. If technical inefficiency is unexpected, we can use the expected profit maximization argument of Zellner, Kmenta, and Dreze (1966) to treat inputs as exogenous (Kumbhakar 1987, page 336). If technical inefficiency is known to the firm, estimates of the production function parameters obtained directly from the profit function will be inconsistent. See Schmidt (1985) and Kumbhakar (1987) for additional discussion.

19. The two-stage approach measures changes in efficiency from ITQs by testing the significance of the year dummies (D_{88}, D_{91} and D_{94}) in the Tobit regressions. If year dummies were incorporated in the stochastic frontier, as well as the second-stage regressions, the effect of privatizing the fishery would already be accounted for in the efficiency scores in the first stage. In addition, we elected to not simultaneously estimate both the stochastic production frontier and the technical inefficiency equation. This “one-stage” estimation procedure is inappropriate in our case because we fix capital (vessel size) and then calculate short-run cost efficiency measures accounting for the short-run economies of scale. Moreover, we also evaluate the relationship between short-run allocative cost efficiency, overall cost efficiency, and single-factor technical and allocative cost efficiency and the dummy variables for vessel size class and years. It is unclear what the effect would be on these short-run efficiency measures and their (second-stage) regressions if the long-run stochastic production frontier and “long-run” technical inefficiency were estimated simultaneously in a one-stage routine. Finally, gains in econometric efficiency for the second-stage regressions were not possible from Tobit regressions in a system of equations, estimated by the method of Zellner’s seemingly unrelated regressions, because the regressors in all of the cost efficiency equations were identical and there were no cross-equation constraints.

20. This approach gives a two-way analysis of variance, accounting for the censoring of the efficiency scores. Estimated regression coefficients are mean values of the efficiency scores for the given category. Standard errors give the within variation for each category.

21. A likelihood ratio (LR) test was performed to test the null hypothesis of a one-sided error term. Using the critical value in Table 1 of Kodde and Palm (1986) and the calculated LR of 3.555, the null hypothesis could not be rejected at the 5% level of significance.

22. The optimal scale of operation is often measured by scale efficiency using a marginal cost definition with economically efficient marginal cost (Førsund, Lovell and Schmidt 1980), where a firm is scale efficient if its output price equals economically efficient marginal cost. In a fishery with fully transferable and divisible private harvesting rights, a profit maximizing fisher should, in each time period, set the supply so that the output price equals the marginal harvesting cost plus the lease price of the harvesting right (Grafton 1995). If the property right is not fully divisible, however, fishers are unable to adjust their production at the margin and "fine tune" their operations to be scale efficient.

23. The economically efficient short-run costs were obtained using the factor demands as defined by Kopp and Diewert (1982) and Taylor et al. (1986). Although the efficient producer surplus and unit rents are calculated differently, Tables 6-10 indicate that they provide very similar results.

24. Casey et al. (1995) in their study of the BC halibut fishery also observed that the principal benefits of ITQs were in terms of the revenues rather than the costs of fishers.

25. Greene (1993, page 89) notes that if the production function is homogeneous of degree "r", then the inefficiency term estimated from a cost function is 1/r times the counterpart from the production function. That is, the estimated inefficiency obtained in the context of a cost function can be translated into a Farrell measure of technical inefficiency by multiplying it by r. This is also seen from Eq. (4) of Lovell and Schmidt (1979). The inefficiency measure from a Cobb-Douglas production function can be multiplied by 1/r and then converted to a technical cost efficiency measure by the approach of Battesse and Coelli (1988). Thus, to estimate long-run technical cost efficiency we started with the firm-level technical inefficiency measures from the estimated production function and adjusted by the long-run measure of homogeneity, the sum of the production coefficients for labor services (L), fuel consumption (F) and capital (K) in Eqn. 1.

26.The rents in the fishery can be obtained using GAMS (Brooke et al. 1996) from a model which maximizes, with respect to $y_{i,,}$ $[P_i - 0.5\phi_i(y_i)]y_i$ summed over all vessels and subject to the constraint that the sum of y_i is less than or equal to the TAC where y_i denotes the transferable quota for vessel i, P_i denotes the ex-vessel price of halibut for vessel i, $\phi_i(y_i)$ is the virtual price for vessel i, and TAC represents the total allowable catch. The objective function provides a piecewise linear approximation to the market inverse derived demand function between the vertical intercept (the unit rent corresponding to zero output, which is zero for the Cobb-Douglas supply function) and the equilibrium ITQ price (determined where the market inverse derived demand curve intersects the perfectly inelastic industry supply curve (the total allowable catch). In equilibrium after quota trade, all unit rents are equalized at the margin across all firms, and if all vessels face the same competitive output price, the virtual price is equalized at the margin across all firms, where the virtual price provides the marginal opportunity cost of production. See Squires and Kirkley (1995) for a further discussion on price endogenous mathematical programming with ITQs.

27. Rucker et al. (1995) in an analysis of the U.S. flue-cured tobacco industry also found that allowing intercounty trades of tobacco quota only led to small changes in overall producer surplus between 0.6 and 3.8 percent over the period 1977 to 1986. Nevertheless, they find allowing intercounty transfers would have an important impact on the incomes of quota owners and growers and the location of production.