Capacity utilization measures and excess capacity in multi-product privatized fisheries

Diane P. Dupont [a],*, R. Quentin Grafton [b,1], James Kirkley [c], Dale Squires [d]

[a] *Department of Economics, Brock University, 500 Glenridge Avenue, 415 Taro Hall, St. Catharines, Ont., Canada L2S 3A1*
[b] *Department of Economics, University of Ottawa, Ottawa, Ont., Canada*
[c] *Virginia Institute of Marine Sciences, College of William and Mary, Williamsburg, VA, USA*
[d] *United States National Marine Fisheries Service, La Jolla, CA, USA*

Abstract

Using individual firm data from before and after the introduction of individual transferable quotas (ITQs) in the Nova Scotia mobile gear fishery, data envelopment analysis (DEA) is used to examine capacity and capacity utilization (CU). This paper is the first to look at CU in a multi-species fishery with both ITQ and non-ITQ components. The paper examines how a change in the property rights regime can affect a multi-product industry and the consequences in terms of product-specific CU, as well as aggregate CU. The results provide insights to regulators interested in using market-based approaches to improve efficiency in multi-product industries. © 2002 Elsevier Science B.V. All rights reserved.

JEL classification: Q22; C61

Keywords: Capacity utilization; Multi-product fishery; Individual vessel quota; Data envelopment analysis

1. Introduction

The world's fisheries are currently threatened on many fronts, one of the most important of which is declining fish stocks because of past regulatory actions and recent environmental changes that have led to excess capacity in fish harvest production. To help improve

---

* Corresponding author. Tel.: +1-905-688-5550/ext. 3129; fax: +1-905-688-6388.
E-mail address: ddupont@spartan.ac.brocku.ca (D.P. Dupont).
[1] Present address: Center for Resource and Environmental Studies, The Australian National University, Canberra, ACT 0200, Australia.

efficiency in the harvesting sector and reduce overcapacity, several nations—including Australia, Canada, New Zealand, and Norway—have implemented privatization schemes intended to replace ineffective input-based restrictions. Rights-based management schemes create individual harvesting rights or individual transferable quota (ITQ) rights (Grafton et al., 1996; National Research Council, 1999). By giving the vessel-owner, a property right to catch a specified amount of fish, the ITQ encourages the economic rationalization of commercial fisheries in two complementary ways. First, fishers are given incentives to catch fish at the least cost, and choose a level of fixed and variable inputs that maximize their individual returns per unit of quota (Scott and Neher, 1981). Second, transferability of quota permits fishers with lower production costs to buy quota from others, and thus, reduce the number of vessels in a fishery.

The ability of an ITQ program to reduce excess capacity is dependent upon the existing level of excess capacity, irreversibilities in investments in fishing capital,[2] the alternatives available for capital and labor outside of the ITQ fishery, intervention by regulators, and time. However, the evidence to date in support of the beneficial impact of ITQs upon excess capacity is widespread. In many fisheries where excess capacity has been considered a problem, the number of active fishing vessels has declined (with differing speeds of adjustment) with the introduction of private harvesting rights (National Research Council, 1999).

While the benefits and difficulties of ITQs as a management regime for fisheries have been assessed by many researchers (Grafton et al., 1996; Burke, 1999; National Research Council, 1999; Kaufmann et al., 1999), virtually no attention has been given to evaluating changes in fishing capacity brought about by the introduction of individual harvesting rights. An exception is Squires et al. (1999). They examine changes in capacity associated with the introduction of private harvesting rights in the (single-species) British Columbia halibut fishery. They find that ITQs resulted in a significant increase in capacity utilization (CU) per vessel per day for large vessels.

In this study, we examine harvesting capacity in Canada's Scotia–Fundy mobile gear, multi-output, groundfish fishery that has been subject to a system of ITQs since 1991. Our study examines the relationship between ITQs, excess capacity, and CU. We employ data envelopment analysis (DEA) to identify vessel-level, product-specific capacity output and CU measures for each of three ITQ species, along with two non-ITQ species. Using these vessel-level measures, along with overall catch quota information, we are able to calculate the extent of excess capacity at the fleet level both pre- and post-ITQ. The results provide preliminary answers to the following questions. First, to what extent was fishing capacity both at the vessel and aggregate level reduced in the fishery after the introduction of ITQs? Second, given the heterogeneous nature of the fishing vessels in the fleet, to what extent were there differences in these reductions according to vessel size class? Third, what impact did ITQs have upon CU measures for individual species within a multi-species fishery? More particularly, did excess capacity in the ITQ species spill over into non-ITQ species, thereby requiring an expansion of the original ITQ program into new species?

Our findings suggest that, given the limited time period for which we have data, there is little evidence of significant change in individual, vessel-specific CU measures. However,

---

[2] While irreversibilities are an important issue, they are not addressed in this paper due to the restrictions of the data set.

there is a greater degree of heterogeneity in the post-ITQ fleet in terms of CU. In particular, larger boats have higher levels of CU. Moreover, extrapolating to the current fishery, we find a reduction in overall fleet capacity.

2. Definitions: fishing capacity, capacity utilization, and excess capacity

2.1. Fishing capacity

While fisheries economists have been concerned with the measurement of fishing capacity, much of the previous literature has equated it solely with the capital stock (vessel and gear) used in the harvesting sector (Kirkley and Squires, 1999). Under this limiting interpretation, capital is treated as homogeneous, and the prescription for reducing excess fishing capacity is to reduce the capital stock, usually with some form of buy-back scheme, whereby the government pays the vessel-owner to remove the vessel from the fishery. This type of analysis does not capture the presence of excess labor, fuel usage and or other inputs for a given capital stock, which is an important part of capacity.

The approach taken in the current paper is less restrictive than in previous research. Specifically, we adopt Johansen's (1968) definition of capacity output. This is the maximum level of production that the fixed inputs are capable of supporting when the variable inputs are fully utilized. Under this definition, capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of capital or other fixed inputs, existing regulations, the state of technology, and other technological constraints.[3]

The Food and Agriculture Organization (FAO) of the United Nations recently endorsed the approach defined above. The FAO's (1998, 2000) accepted definition of fishing capacity is "... the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully-utilized, given the biomass and age structure of the fish stock and the present state of the technology". While the FAO definition focuses upon the fleet as a whole, it treats fishing capacity as the short-run concept described above where fishers face constraints in terms of the resource stock and their use of fixed inputs. Thus, capacity measures change with stock fluctuations in a stock-flow production technology. The FAO definition may be seen as a technological measurement of capacity because it is equivalent to productive efficiency at full utilization of the variable inputs Klein and Long (1973). However, this measure is "economic" in a sense by virtue of the fact that the observed data implicitly reflect market behavior and decisions and the consequence of this is that a true physical maximum is not actually being imputed (Kirkley and Squires, 1999).

2.2. Capacity utilization

CU represents the proportion of available capacity that is utilized, which is measured by the ratio of actual output to capacity output (Morrison, 1985; Nelson, 1989). Adoption of the technological concept of capacity output described above means the use of the level of

---

[3] Capacity output is efficient output when variable input use is unconstrained. However, what is generally conceived of as efficient output is evaluated at observed input levels, rather than unconstrained levels.

output attainable by "full utilization" of the variable factors of production, given the current technology and keeping fixed factors at their current levels. Thus, the analysis is restricted to observed output–input relationships. Using the definition adopted by the FAO, full CU represents full capacity and cannot exceed one. A CU less than one indicates that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers, 1966).

2.3. Excess capacity

At the fleet level in this renewable resource industry, CU is a less useful concept than at the level of the individual vessel because of the focus on sustainable resource use. Instead, at the aggregate level, excess capacity is more informative. Capacity output is obtained for the fleet by aggregating each vessel's capacity (or mean capacity). However, in many oversubscribed fisheries, total fleet output is regulated by a total allowable catch (TAC) constraint. Excess capacity then exists when a fleet has the capability to harvest in excess of a desired or target level of output, such as the TAC (Kirkley and Squires, 1999). In other words, there exists an excessive use of all inputs—including labor, heterogeneous capital and other fixed factors—to produce a given set of outputs.

3. Case study: the Scotia–Fundy inshore mobile gear groundfishery

3.1. Fishery background

The Scotia–Fundy sector is one of the five management sub-sectors in the Maritimes fisheries region of Canada. The geographical location of this sector extends from the north-eastern tip of Cape Breton to the New Brunswick–Maine border. The sector encompasses the Scotian Shelf and the Bay of Fundy (specifically, DFO Regions 4Vn, 4Vs, 4W, 4X, and parts of 5Y and 5Z). For many decades, groundfish, particularly cod, have been heavily exploited in this sector. Groundfish have typically accounted for 30–40% of the total landed value in the region (DFO Web Statistics, various years).

An important component of the groundfish fishery in the Scotia–Fundy region is the inshore (sometimes called near-shore) mobile gear fleet.[4] The fleet consists of vessels ranging from 35 to 65 ft in length that use otter trawls or Danish seines to fish. During the 1970s and 1980s, productivity and capacity increased in this fishery despite limited entry regulations and various input restrictions. In particular, adoption of the 200-mile limit in 1977 encouraged the purchase of bigger and more powerful vessels between 1978 and 1982. By 1986, and prior to a boom in fleet capacity in 1986 and 1987, the inshore mobile gear fleet had the capability to harvest four times the TAC, which was established using the $F_{0.1}$ level of fishing mortality (Barbara et al., 1995).[5]

---

[4] Other groundfish fleets in the same area are the fixed gear (under 65 ft) fleet, the Eastern Nova Scotia Management fleet, and the off-shore fleet.

[5] $F_{0.1}$ is a constant rate of exploitation of a fishery that is slightly less than that which maximizes the yield per recruit. $F_{0.1}$ is a widely used but ad hoc method of determining the total allowable catch in a fishery (Grafton et al., 2001).

In the late 1980s, managers became concerned about the status of groundfish stocks off Nova Scotia because there was evidence to suggest potentially severe declines in the near future biomass levels of cod, haddock, and Atlantic Pollock.[6] In response, managers closed the Scotia–Fundy inshore mobile gear fishery in mid-year and did not re-open the fishery until 1990. As a result of the closure, a task force was established to examine possible problems associated with excess harvesting capacity and low stock levels. One of the recommendations by the task force was to implement an ITQ program for the fleet, which was introduced in January 1991.

3.2. The privatized (ITQ) fishery

Under the ITQ program, each license holder was given an initial, individual quota allocation (Barbara et al., 1995). The initial allocations were calculated on the basis of the average of the best 2 years harvest during the 1986–1989 fishing seasons. Initially, only some stocks were subject to the ITQ program, namely, 4TVn J-A cod, 4Vn M-D cod, 4VsW cod, 4X/5Y cod, 4TVW haddock, 4X haddock, and 4VWX and 5 pollock. In 1992, however, Georges Bank (5Z) cod and haddock were added. In 1994, flounder was added to the list of ITQ-based species. Each ITQ gave the holder a specific amount of the total inshore mobile gear quota for each particular stock subject to this form of management.

Not all license holders eligible to fish under the ITQ system, however, took advantage of its provisions and only 325 of the original 455 license holders chose to participate in the ITQ fishery in 1991. Of the remainder, six licenses were cancelled entirely, 50 so-called "generalists" chose to pool their individual allocations and to fish the small quota competitively[7], and 74 dual fixed/mobile gear license holders opted out of the mobile gear fishery and became part of the non-quota, competitive fixed gear, groundfish fishery.

At the outset, the program allowed unlimited trading of quota among eligible quota holders, and fishers could acquire quota up to 30 days after landing the catch. In addition, fishers were subject to 100% dockside monitoring by a private company. Initially, the Department of Fisheries and Oceans paid for administration and funding of the dockside-monitoring program, but in 1992, the cost of the program was transferred completely to the fishers.

Since the introduction of the ITQ program, there have been substantial changes, at the aggregate level, to the size of the mobile gear groundfish fleet. These changes have occurred in a manner consistent with expectations regarding the impact of an ITQ program. Namely, the number of active quota holders in the fishery has decreased. At the year-end in 1991 (the end of the first year of the quota program), 321 vessels had licenses with quota shares (i.e. the right to catch fish to some specified limit). At the end of 1998, only 249 licenses continued to have quota shares (Cindy Webster, Commercial Data Division, Fisheries and Oceans, Halifax, personal communication). In addition, the number of active ITQ vessels fell

---

[6] See Dupont and Grafton (2000) for further details.

[7] This portion of the fleet was allowed to fish competitively for the so-called Generalist quota. Thus, the quota system as a whole entailed individual quotas for each of the 325 ITQ participants and an overall Generalist quota for the 50 Generalist vessels. These latter were not allocated a fixed quota, but could catch an aggregate amount of fish up to the specified overall Generalist quota limit.

steadily from 268 in 1991 to 137 in 1998. The number of generalist vessels also decreased from 50 in 1991 to 28 in 1998.

In part, the change in the number of generalist vessels was a response to the introduction of ITQs for flounder in 1994. These generalist vessels primarily fished flounder in 1991 and caught cod and haddock only as by-catch. Although ITQs were required for harvesting both cod and haddock, the quantities caught of these quota species were small enough that operators of the generalist vessels were willing to fish these species competitively from a pooled allocation of their own ITQs. Given the reductions in overall quota for these species due to biomass declines, the competitive fishing system broke down. As a result, almost half of the original 50 generalist vessels withdrew from the generalist pool in order to be able to fish their own ITQs.

3.3. Fishery data

The data available for an examination of CU and excess capacity in this fishery include vessel-specific data from three different fishing years: 1988, 1990 and in 1991, the year the ITQ program was introduced into the fishery.[8] Data include gear ownership and vessel characteristic information obtained from the Vessel Performance Questionnaire implemented by DFO and made available by the DFO Program Coordination and Economics Branch, Scotia–Fundy Region. The coverage of vessels varies by year. For 1988, the information is available on 42 individual vessels, which represents 11% of the entire licensed fleet at that time. For 1990, data on 66 vessels are used, and for 1991, the data are for 81 individual vessels, which represent 26% of the total number of active vessels in the fishery in that year.

4. A practical approach to measuring capacity and capacity utilization in the fishery: DEA

In this paper, we propose the use of DEA, a mathematical programming technique, as a practical approach to determine the maximal or capacity output per fisher in the Scotia–Fundy mobile gear groundfishery. The DEA methodology derives a production frontier that describes the most technically efficient combination of outputs given the state of fishing technology and the fish stock and unrestricted variable inputs. Färe (1984) introduced this methodology as a means of measuring a technological–economic concept of capacity and CU for manufacturing firms. This notion was later operationalized by Färe et al. (1989, 1994). Most recently, Kirkley and Squires (1999) proposed DEA as a useful approach for assessing capacity in fisheries.

Given the characteristics of the Scotia–Fundy fishery, we need to distinguish between variable and fixed factors and allow for multiple outputs and variable returns to scale. We employ a model proposed by Färe et al. (1989). They posit that capacity at the plant (fisher) level can be estimated by partitioning inputs according to whether they are fixed

---

[8] Further data points subsequent to the introduction of the ITQ program would have been preferable, however, these years are, unfortunately, the only ones for which vessel level data were collected by the Department of Fisheries and Oceans, 1998, Canada.

(F_x) or variable (V_x) and then solving an output-oriented, DEA problem in which only fixed factors bind production. We assume that there are $j = 1, \ldots, J$ fishers producing M outputs (catches of different species) by means of both fixed and variable factors. We let u_{jm} equal the quantity of the mth output produced by the jth producer, and x_{jn} be the level of the nth input used by the jth producer. The DEA problem to be solved is found in Eq. (1), where θ is a measure of technical efficiency (TE) and $\theta \geq 1.0$.[9] If we multiply the observed output by θ, we obtain an estimate of capacity output.

$$\begin{aligned}
&\text{TE}_{ocj} = \max_{\theta, \lambda, z} \theta \quad \text{subject to} \\
&\theta u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, \quad m = 1, \ldots, M; \qquad \sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \quad n \in F_x; \\
&\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \quad n \in V_x, \\
&z_j \geq 0, \quad j = 1, \ldots, J, \quad \text{and} \quad \lambda_{jn} \geq 0 \\
&\sum_{j=1}^{J} z_j = 1.0.
\end{aligned} \tag{1}$$

The first constraint in the above equation (second line) imposes convexity on the production set. The second constraint (third line) requires variable inputs to be fully utilized, while the third constraint (fourth line) allows fixed inputs not to be fully utilized. Finally, the last constraint allows for the presence of variable returns to scale.

In the empirical analysis, output was specified as the round weight of each species landed (kg) per vessel per day fished. The fixed input was specified as the capital stock of each vessel and measured by its length overall (LOA). The DEA model also included biomass levels for cod, haddock, and pollock as additional fixed environmental parameters (z variables), where the biomass of each species was divided by the number of days fished by each vessel to be consistent with the specification of output on a daily basis. The inclusion of the biomass data controlled for changes in resource abundance that provided discrete shifts in the stock-flow harvesting technology.

Alternative methods for measuring capacity and CU have been proposed in the literature, most particularly stochastic production frontiers and duality-based measures relying upon cost functions (Morrison, 1985; Berndt and Fuss, 1989; Nelson, 1989; Segerson and Squires, 1990). In contrast to these other methods, DEA does not impose an underlying functional form and thus estimates are not conditional upon the functional specification. Until recently, DEA has also been the only approach to permit an examination of technical efficiency and capacity in a multiple-product environment without imposing separability assumptions on the outputs.[10] DEA can be used when prices are difficult to define or behavioral assumptions, such as cost minimization, are difficult to justify (Coelli et al., 1998), although the other primal econometric method—the stochastic production frontier approach—shares this advantage. In addition, the DEA output makes it easy for the researcher to calculate capacity output for each individual species where the sum of the

---

[9] Strictly speaking, this measure is the reciprocal of an output distance function and is, therefore, an output-orientated measure of technical efficiency evaluated when variable inputs are binding due to their full utilization. Färe and Grosskopf (2000) have recently proposed a more general DEA method for capacity and capacity utilization using the directional distance function. This is more general than the output distance function approach.

[10] The recent multiple output stochastic distance function work by Paul et al. (2000) offers another alternative which does not impose separability.

individual capacities for a given output, overall firms in a relevant region and time period, provides a measure of fleet capacity for each output. Excess capacity measures can then be determined on a species-by-species basis.[11] Such a feature is important in an industry where multiple products are the norm.

Before leaving the discussion about the DEA methodology, it would be appropriate to identify its weaknesses. First, it is a non-statistical approach, and therefore, statistical tests of hypotheses about structure and significance of estimates cannot be easily conducted (Coelli et al., 1998), although we propose a two-stage approach later in the paper to address this issue. In our case, however, rather than use a simple regression of efficiency scores on a group of likely determinants, we undertake an analysis of variance. This is because we were interested in evaluating the changes over time by size class of vessel, rather than determinants of efficiency. Second, because DEA is non-statistical, all deviations from the frontier are assumed to be due to inefficiency.[12] Third, estimates of capacity and CU may be sensitive to the particular data sample.

5. Results

5.1. Impact of ITQs upon capacity and capacity utilization at the vessel level

When a technology is comprised of both multiple outputs and fixed factors, measures of capacity and CU become more difficult to obtain (Berndt and Fuss, 1989). Given the stock-flow production technology of a fishery, with only one fixed factor (vessel size), resource or fish stocks are conceived as natural capital stocks such that capacity and CU measures are conditional upon these resource stocks (Kirkley and Squires, 1999).[13]

Table 1 provides the basic output from the solutions to the DEA model described in Eq. (1). Namely, we obtain estimates of capacity on a per vessel per day fished basis. We calculate this for three ITQ species. These are cod, haddock, and pollock. As well, we calculate these per vessel per day measures for two other non-ITQ species groupings—

---

[11] While "economic" or cost-based models would pose a problem for the determination of the optimum cost point in terms of multiple outputs and inputs, the stochastic frontier approach could also be used to determine excess capacity measures on a species-by-species basis.

[12] The use of annual data in this regard is beneficial since some of the variation that one might observe in daily outputs (catches) due to weather or mechanical failure is smoothed out.

[13] When resource stocks are conceived of as natural capital stocks and an asset, they could be construed as fixed inputs in a neoclassical production technology. However, in an analysis rooted in the theory of the firm, the resource stocks can be specified as a technological constraint on the individual firm's stock-flow production technology because the stock's abundance affects the production environment within which firms operate but remains beyond the control of any individual firm (Squires, 1992). Conventional inputs such as capital, labor, energy, and materials are organized conditional upon expected resource stock abundance levels to generate the extractive flow or catch. This approach does not preclude managing the fishery as if the resource stocks were assets, but the framework does properly specify the resource stock just like any other environmental parameter, as a technological parameter, instead of an input beyond the control of individual firms. See pp. 60–62 of McFadden (1978) for additional discussion of environmental parameters specified as technological constraints in the firm's production technology. Whether the resource stocks are treated as fixed inputs or technological constraints, capacity is conditional upon the levels of the resource stocks.

Table 1
Summary statistics on all sample vessels in the Nova Scotia mobile gear groundfishery (1988, 1990, 1991)[a]

Variable	1988		1990		1991	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
LOA (ft)	49.71	9.40	50.76	9.15	49.69	9.17
Total days at sea	109.67	39.99	96.39	36.19	100.48	34.61
CU	0.724	0.237	0.649	0.244	0.653	0.273
Cod capacity (daily)	1673.79	1098.10	2044.19	1224.52	1636.99	1142.82
Haddock capacity (daily)	813.89	578.75	576.00	406.76	501.70	372.44
Pollock capacity (daily)	617.00	527.88	566.68	508.71	538.62	679.57
Flounder capacity (daily)	527.36	506.78	800.96	663.71	692.48	603.76

[a] Each species capacity output is measured in kilogram of fish per day at sea.

flounder and a Divisia index for all other species, including shellfish. Mean values and standard deviations for a number of variables of interest for the three ITQ species, as well as flounder—which subsequently in 1994 become subject to ITQ provisions—are found in Table 1. These variables include the fixed factor (length overall) and a variable factor indicating the number of days at sea. In addition, information on capacity for each of the species of interest is included. Because the model uses per day output measures, capacity per day measures were multiplied by the number of days at sea to obtain annual capacity measures.[14] This approach gives full utilization of the variable inputs and accounts for the annual differences in season length, especially before and after the introduction of ITQs. As Table 1 shows, capacity in each of the three ITQ species fell from 1988 to 1990 and then rose marginally from 1990 to 1991.

In order to account for the multi-species nature of the fishery, we calculate an aggregate CU measure per vessel in the following way. First, we calculate a ray measure of capacity output for each species. Second, we allow for the presence of output slack variables in a second-stage linear programming problem to derive capacity output for each species in which output slacks are zero. Capacity output j can be denoted as μ_j^*, where $\mu_j^* = \theta\mu^* + S_j$, where S_j corresponds to the non-proportional slack variables (Ali and Seiford, 1993).[15] The capacity output for each species is a non-radial measure because it is comprised of a residual non-proportional output slack variable computed following the proportional (ray) expansion of all outputs (Koopmans, 1951; Coelli et al., 1998). Finally, we aggregate these individual capacity outputs for each species using their revenue shares as weights to obtain the weighted average. This, then is an aggregate measure of capacity output. Aggregate

---

[14] The use of per day output measures is appropriate when there are significant differences in season length across the different years for which data are available. In fact, this type of adjustment did occur with the shift to ITQs. If this were not taken into account by using per day output measures, then our measures of capacity between periods would not be directly comparable.

[15] Coelli et al. (1998, p. 142) observe that Farrell (1957) defined technical inefficiency in terms of the radial reduction in inputs that is possible, whereas Koopmans (1951) provided a more strict definition of technical efficiency which is equivalent to stating that the firm is only technically efficient if it operates on the frontier and furthermore that all associated slacks are zero. In our capacity study, capacity and CU measures, both product-specific and aggregate, correspond to an output-oriented Koopmans technical efficiency measure (with full variable input utilization).

CU per vessel is obtained by dividing observed output by the measure of capacity output for each vessel. The procedure gives homothetic output separability (Segerson and Squires, 1990).

As Table 1 shows, mean CU fell sharply from 1988 to 1990, then recovered marginally. However, the 1991 mean CU was only 0.65. Thus, on a daily basis, vessels did not fully utilize their capacity over the entire period 1988–1991. In addition, the standard deviation of CU increased over the same period, thereby indicating a greater diversity of production by vessels in the fishery post-ITQ.

We separated our data samples into two groups corresponding to regulatory-induced size categories, in order to examine more closely this issue of greater heterogeneity in the fishery since the introduction of the ITQ program. The regulator distinguishes between small vessels—between 25 and 45 ft length overall—and large vessels—between 45 and 65 ft length overall.[16] Large vessels might be in a more advantageous position with the introduction of ITQs because they may enjoy economies of scale through the sale of quota over the fishing season.

Table 2 reports the mean values and standard deviations for the same variables as in Table 1, however, these values are presented separately for small and large vessels. Values for large vessels are in bold, while those for small are not bolded. CU fell sharply for small boats over the 1988–1990 period and then fell slightly between 1990 and 1991. CU measures for large vessels followed the same general pattern for the first period of comparison but deviated from the pattern for the last period. CU for these larger vessels exhibited an upward climb in 1991 compared to 1990, but the mean CU in 1991 was still below the 1988 mean CU value. As expected, CU measures for large vessels were consistently much higher than those for small vessels.

There was a divergence in product-specific capacity measures for the two vessel types over the period (Table 2). Capacity for large vessels rose in pollock and flounder, while falling for small vessels. For cod and haddock, both vessel types followed the same pattern of steep fall (from 1988 to 1990) followed by partial recovery from 1990 to 1991. While we cannot conclude unequivocally that the ITQ program improved capacity and CU, from looking at the declining pattern prior to 1991, it is a reasonable conclusion that the ITQ prevented a worsening of capacity and CU in the fishery.

While the mean values in Table 2 give a snapshot of the fishery, they may mask the presence of heterogeneity. Indeed, Table 2 shows evidence of increasing variability in the mean values after the introduction of ITQs. To examine this phenomenon, we calculated the frequency distributions for CU measures for large and small vessels separately for each of the 3 years, as reported in Table 3. The dispersion appears to be higher among the small vessels than among the large vessels (Table 3). If we take the proportion of vessels in each year that is in the two highest deciles, we find that 46% of small vessels were in the (highest) deciles of 0.8 and 1.0. In 1990, this percentage declined to 31%, but it rose sharply in 1991

---

[16] In Atlantic Canada, vessel licenses are denominated by vessel length. Vessels under 45 ft length are normally considered as part of the inshore fleet that typically work close to the shore and use fixed gear. Vessels of 45–65 ft are normally defined as the near shore fleet and include vessels that use mobile gear. The mid-shore fleet is defined as those vessels of 65–100 ft in length and the off-shore fleet are vessels greater than 100 ft in length (Grafton, 1996, pp. 149–150).

Table 2
Summary statistics for small and large vessels[a]

Variable	1988		1990		1991	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
LOA (ft)	43.19/**60.31**	1.74/**6.54**	43.03/**58.48**	1.53/**6.68**	42.81/**59.21**	1.74/**6.25**
Total days at sea	103.65/**119.44**	33.51/**48.32**	93.18/**99.61**	34.90/**37.71**	96.70/**105.71**	36.72/**31.22**
CU	0.668/**0.815**	0.245/**0.198**	0.635/**0.664**	0.264/**0.225**	0.610/**0.714**	0.283/**0.249**
Cod capacity (daily)	1456.07/**2027.58**	1034.72/**1138.36**	1470.28/**2618.10**	1146.43/**1025.73**	1243.35/**2181.12**	966.81/**1156.49**
Haddock capacity (daily)	695.39/**1006.46**	496.22/**664.27**	463.24/**688.76**	411.63/**374.72**	412.28/**625.29**	374.71/**336.79**
Pollock capacity (daily)	547.40/**730.10**	544.28/**495.88**	332.69/**800.67**	431.43/**476.01**	234.79/**958.63**	324.27/**812.25**
Flounder capacity (daily)	645.70/**335.06**	579.17/**281.44**	975.36/**626.57**	792.33/**451.97**	754.95/**606.11**	606.68/**597.82**

[a] Each species capacity output is measured in kilogram of fish per day at sea. Numbers in bold are for large vessels (between 45 and 65 ft LOA) in sample, while unbolded numbers are for small vessels (between 25 and 45 ft LOA) in sample.

Table 3
Frequency distribution of aggregate CU by vessel size class

Range	1988		1990		1991	
	Small	Large	Small	Large	Small	Large
0.90–1.00	9	8	9	7	12	12
0.80–0.89	3	0	2	2	6	8
0.70–0.79	2	6	4	5	4	0
0.60–0.69	2	0	5	3	6	4
0.50–0.59	1	1	4	5	3	3
0.40–0.49	7	0	4	5	3	3
0.30–0.39	2	1	4	1	7	1
0.20–0.29	0	0	3	1	1	3
0.10–0.19	0	0	1	1	5	0
Total observations	26	16	36	30	47	34

to 38%. The pattern is similar for large vessels, with the percentages being 50, 30, and 58% in 1988, 1990 and 1991, respectively. Thus, for large vessels, the first year of the ITQ program had the largest percentage of vessels in the two highest CU deciles.

5.2. Testing for changes in capacity and capacity utilization

The effects of ITQs on the production process and incentives of fishers, through elimination or reduction of the technological stock and congestion externalities, were evaluated through an analysis of variance. In a second stage analysis, vessel-specific capacity and CU measures obtained from the DEA analysis were regressed upon dummy variables for year and vessel size class. This approach captures the effect that ITQs have on the actual production process and incentives of fishers. These measures capture average maximum potential output per day (average product per unit of effort) rather than fisher behavior at the margin.

In the second-stage analysis of variance, the explanatory variables were the product of annual dummy variables for 1988 (D88) 1990 (D90) and 1991 (D91) and dummy variables for the two size classes of vessels. Thus, we were tracking cohorts of vessels defined by vessel size class. Tobit regressions were used because they allowed for censoring of the dependent variable, CU, at 0 and 1. When each species' capacity output is the dependent variable, the Tobit regression allows for the possible censoring of capacity output at 0, because under joint harvesting of multiple species, not all species are necessarily harvested. Each equation was estimated separately, rather than as a system utilizing Zellner's seemingly unrelated regression, because the independent variables in each equation were the same (Kmenta, 1971). This approach allows us to account properly for the data set as a time series of cross sections rather than as a panel data set, in which cohorts are tracked over time rather than individual firms (Deaton, 1995).

The effects of "privatizing the fishery" are evaluated by significance tests of the null hypothesis of no changes in CU or capacity output between three pairs of time periods (1988–1990, 1990–1991, and 1988–1991) and for a given vessel size class or cohort (large

and small). Thus, D88SM − D91SM = 0 tests the null hypothesis of equal CU (or a given species capacity output) for small vessels between 1988 and 1991. For Tobit regressions, the appropriate test of the hypotheses of no change in capacity and CU is the Wald test using a χ^2 statistic. If the χ^2-value is significant for CU or a species capacity output measure (given a single linear restriction and hence one degree of freedom), then the null hypothesis of equal capacity for a species or CU is rejected.

Table 4 shows the product-specific capacity measure tests using a 5% level of significance for the three species initially subject to ITQs (cod, haddock, and pollock), and flounder which subsequently was brought into the ITQ program.[17] The important results with respect to the ITQ fisheries are that cod capacity increased over the 1988–1990 period for large vessels in the fleet but not over the period 1988–1991. The sign change was negative, but insignificant, for small vessels. The haddock capacity fell significantly for both large and small vessels over the 1988–1990 period. The pollock capacity fell significantly for small vessels over the 1988–1991 period and rose (although not significant) for large vessels. Thus, capacity changes for the two of the three ITQ species were significant over the period. Furthermore, flounder capacity increased significantly over the 1988–1990 period for small vessels and increased for large vessels over the 1988–1991 period, although this is significant only at the 10% level. This suggests that vessels subject to ITQs on certain species may consider adding non-ITQ species to their catches, thereby imposing additional fishing pressure upon these species. This may ultimately lead to a proliferation of ITQs in multi-species fisheries. The approach for measuring product-specific capacity measures adopted for this paper may be useful in determining which particular species would be at risk.

Table 5 provides the results of the Tobit regressions of aggregate CU regressed upon the interaction of the year and vessel cohort dummies. The null hypothesis is that CU was the same for a year/cohort pair. Results of the statistical tests indicate very little significant change between the 3 years (1988–1991). The only significant differences across the periods were CU for large vessels, which fell significantly over the period 1988–1990. The difference between small and large vessels in the CU was also found to be significant in 1991, the first year that ITQs were introduced into the fishery, at a 10% level of significance. The evidence suggests that large vessels had significantly greater CU rates than did small vessels. The result supports the hypothesis that the ITQ program may have promoted efficiency more for the large vessels than small vessels because of their greater scope in modifying their operations.

5.3. Measuring excess capacity

The aggregate impact of fleet capacity is provided in Table 6. The total annual fleet capacity for cod was calculated by multiplying cod capacity per vessel per day (a non-radial

---

[17] We also did tests on product-specific capacity utilization measures. They are not reported in the interests of space. In most cases, the tests results showed no significant difference between various vessels size and year class combinations. The only exceptions were for cod and haddock for large vessels in 1988–1990 and, again for large vessels pursuing haddock in 1988 and 1991. In each case, capacity utilization had fallen in the later period. The only cases where capacity utilization had risen in the later period were for large vessels in 1990–1991 for cod, haddock, and pollock and for small vessels pursuing pollock between 1990 and 1991.

Table 4
Analysis of variance—is capacity by species the same by year and vessel size class?[a]

Null hypothesis	Cod capacity			Haddock capacity			Pollock capacity			Flounder capacity		
	Sign change[b]	Signi-ficant	Reject null? 5% (Y/N)	Sign change	Signi-ficant	Reject null? 5% (Y/N)	Sign change	Signi-ficant	Reject null? 5% (Y/N)	Sign change	Signi-ficant	Reject null? 5% (Y/N)
88S = 90S	+	0.96	N	−	0.03	Y	−	0.10	N	+	0.03	Y
88S = 91S	−	0.41	N	−	0.01	Y	−	0.01	Y	+	0.45	N
90S = 91S	−	0.34	N	−	0.59	N	−	0.46	N	−	0.10	N
88L = 90L	+	0.07	N	−	0.01	Y	+	0.66	N	+	0.10	N
88L = 91L	+	0.63	N	−	0.01	Y	+	0.15	N	+	0.13	N
90L = 91L	−	0.09	N	−	0.53	N	+	0.21	N	−	0.89	N

[a] Small vessels less than 45 ft in overall length and are represented by the symbol 'S'. Large vessels greater than or equal to 45 ft and less than or equal to 65 ft in overall length and are represented by the symbol 'L'. Capacity measured in kilogram per vessel per total days at sea with all gear types.

[b] Sign change represents the sign change going from the item on the left-hand side of the equality sign to the right-hand side. For example, 88S = 90S, the sign change is positive, indicating that the cod capacity for small vessels increased in 1990 relative to 1988.

Table 5
Analysis of variance—is capacity utilization the same by year and vessel size class?[a]

Null hypothesis	Aggregate capacity utilization[b]			
	Sign change	χ^2	Significant	Reject equality? (Y/N)
88S = 90S	−	0.15	0.70	N
88S = 91S	−	0.95	0.33	N
90S = 91S	+	0.36	0.55	N
88L = 90L	−	4.72	0.03	Y
88L = 91L	−	2.24	0.13	N
90L = 91L	+	0.75	0.39	N
88S = 88L	+	3.85	0.05	Y
90S = 90L	+	0.07	0.80	N
91S = 91L	+	3.32	0.07	N

[a] Small vessels less than 45 ft in overall length and are represented by the symbol 'S'. Large vessels greater than or equal to 45 and less than or equal to 65 ft in overall length and are represented by the symbol 'L'.

[b] Aggregate capacity utilization is kilogram per vessel per total days at sea. Test results are at 5% significance level, 'Y' means equality is rejected. Sign change is the change in the sign of capacity utilization from the first item identified in the null hypothesis.

measure) by the mean number of days in the season and the number of vessels in the fleet. Cod fleet capacity was 83,523 metric tons (mt) in 1988, which increased to 89,653 mt in 1990 but declined to 61,682 mt in 1991. The haddock fleet capacity declined steadily from 40,613 mt in 1988 to 18,904 mt in 1991, and pollock fleet capacity fell from 30,788 mt in

Table 6
Aggregate capacity and excess capacity in the ITQ fisheries (in mt)

Year/species	Capacity[a] (mt)	TAC[b] (quota in 1991)	Excess capacity[c]
Cod capacity			
1988	83522	42797 (actual catch)	40725
1990	89653	39322 (actual catch)	50331
1991	61682	17128 (quota)	44554
Haddock capacity			
1988	40613	16165 (actual catch)	24448
1990	25262	11209 (actual catch)	14053
1991	18904	By-catch only	18904
Pollock capacity			
1988	30788	14254 (actual catch)	16534
1990	24853	14257 (actual catch)	10596
1991	20295	9839 (quota)	10456

[a] Capacity is found by taking the product-specific capacity output per day per vessel, multiplying this by the average number of days for a particular year from Table 1, and then multiplying the result by the number of vessels in the fishery in that year. For 1988 and 1990, the number of vessels is 455 (estimate from DFO) and for 1991 the number of vessels is 375 (the number of quota-holding vessels in the fishery).

[b] TAC is total allowable catch. This is taken to be the actual catch in each of the pre-ITQ years. But for 1991, the TAC is assumed to be the allowable quota for the fishery.

[c] Excess capacity is the difference between the capacity and the TAC (or quota).

1988 to 20,295 mt in 1991. Most of the decrease came about from the combination of a lower capacity per vessel per day and the decline in vessel numbers due to the introduction of ITQs in 1991. Overall, very little changed in the average number of days fished per vessel over the period.

Given that excess capacity appears to be greatly affected by the number of vessels, we can look both at the first year of the ITQ program and then extrapolate beyond the data set to examine the likely impact of ITQs since 1991. For the Scotia–Fundy mobile groundfishery, there has been fairly substantial excess capacity for each of the three ITQ species (cod, haddock, and pollock) at the aggregate level. In 1988, excess capacity for each of the species was over 50%. By 1991, although actual capacity for the cod fishery had fallen by 26%, excess capacity had risen slightly. The increase is likely attributable to the rapid decline in biomass that substantially reduced the total allowable quota available for this species. For the other two ITQ fisheries (haddock and pollock), however, substantial reductions in both actual capacity and excess capacity were observed. This was largely driven by the presence of the ITQ program that promoted the exit of 80 vessels from the groundfishery, or about 18% of the pre-ITQ fleet size.

Since 1991, more vessels have either left the fishery or become inactive. For example, 2 years after the ITQs were introduced, only 255 vessels were active in the fishery. If we assume that daily capacity and the number of fishing days were the same for 1993 as in 1991, then cod capacity, for example, would have been only 46,079 mt. By contrast, the total cod quota was 11,977 mt such that excess capacity would only have been 34,102 t, a 23% decrease in excess capacity from the first year of the ITQ program. Thus, it would appear, for this fishery, that ITQs may be instrumental in encouraging the reduction of excess capacity at the aggregate level.

6. Concluding remarks

This paper has presented the first comprehensive assessment of capacity and CU measures from a DEA of a multi-species fishery. Using data from the Scotia–Fundy mobile gear ITQ groundfishery, mean daily CU measures for large and small vessels and combined were calculated. Although little evidence of significant change in individual, vessel-specific, CU measures exist over the time period—1988, 1990, and 1991, individual harvesting rights appear to have reduced excess capacity in aggregate in the fishery. Moreover, these preliminary results indicate that a change in the property rights have led to a greater degree of heterogeneity of vessels in terms of capacity.

In spite of the limitations of the data, the preliminary results indicate that larger percentages of both large and small vessels in the fishery were operating in the upper deciles of CU than did vessels prior to the introduction of private harvesting rights. Overall, large vessels had higher levels of CU than did small vessels that suggests that large vessels may be better placed to take advantage of changes in their production process.

An advantage of the methodology employed in the study is that it allows the calculation of product-specific capacity and CU measures. Such information can be an important signal to indicate whether the introduction of a private harvesting rights in one species may induce additional fishing pressure upon competitively fished species. The evidence from the Nova

Scotia mobile gear fleet is that capacity for flounder increased for both large and small vessels.

Acknowledgements

References

Ali, A., Seiford, L., 1993. The mathematical programming approach to efficiency analysis. In: Fried, H., Lovell, C.A.K., Schmidt, S. (Eds.), The Measurement of Productive Efficiency: Techniques and Applications. Oxford University Press, Oxford (Chapter 3).

Barbara, R., Brander, L., Liew, D., 1995. Scotia–Fundy inshore mobile gear groundfish ITQ program. Department of Fisheries and Oceans, Mimeo.

Berndt, E.R., Fuss, M., 1989, Economic capacity utilization and productivity measurement for multi-product firms with multiple quasi-fixed inputs. Working Paper No. 2932. National Bureau of Economic Research, Cambridge, MA.

Burke, D.L., 1999. Canadian experience with individual transferable quotas. Presented at the Fish Rights 99 Conference on Use of Property Rights in Fisheries Management, Freemantle, Mimeo, Western Australia, November 1999.

Coelli, T., Rao, D.S., Battese, G., 1998. An Introduction to Efficiency and Productivity Analysis. Kluwer Academic Publishers, Boston, MA.

Deaton, A., 1995. Panel data from time series of cross-sections. Journal of Econometrics 30, 109–126.

Department of Fisheries and Oceans, 1998. Atlantic Coast landed quantities and Atlantic Coast landed values. Web documents linked to the following URL: http://www.ncr.dfo.ca/communic/statistics/.

Dupont, D.P., Grafton, R.Q., 2000. Multi-species individual transferable quotas: the Scotia–Fundy mobile gear groundfishery. Marine Resource Economics 15 (3), 205–220.

FAO, 1998. Report of the FAO technical working group on the management of fishing. FAO Fisheries Report No. 586. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2000. Report of the technical consultation on the measurement of fishing capacity. FAO Fisheries Report No. 615. Food and Agriculture Organization of the United Nations, Rome.

Färe, R., 1984. The existence of plant capacity. International Economic Review 25, 209–213.

Färe, R., Grosskopf, S., 2000. Theory and application of directional distance functions. Journal of Productivity Analysis 13, 93–103.

Färe, R., Grosskopf, S., Kokkelenberg, E.C., 1989. Measuring plant capacity, utilization and technical change: a non-parametric approach. International Economic Review 30, 655–666.

Färe, R., S. Grosskopf, C.A. Knox Lovell, 1994. Production Frontiers. Cambridge University Press, Cambridge, MA.

Farrell, M.J., 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society Series A C20 (3), 253–290.

Grafton, R.Q., 1996. Performance of and prospects for rights-based fisheries management in Atlantic Canada. In: Crowley, B.L. (Ed.), Taking Ownership: Property Rights and Fishery Management on the Atlantic Coast. Atlantic Institute of Markets Studies, Halifax.

Grafton, R.Q., Squires, D., Kirkley, J., 1996. Private property rights and the crises in world fisheries: turning the tide? Contemporary Economic Policy 14, 90–99.

Grafton, R.Q., Nelson, H.W., Pendleton, L., 2001. A Dictionary of Environmental Economics and Ecology. Edward Elgar, Cheltenham, UK.

Johansen, L., 1968. Production functions and the concept of capacity in Recherches récentes sur la fonction de production. Center d'Etudes et de la Recherche Universitaire de Namur.

Kaufmann, B., Geen, G., Sen, S., 1999. Fish futures: individual transferable quotas in fisheries. Fisheries Research and Development Corporation, Kiama, NSW, Australia.

Kirkley, J., Squires, D., 1999. Measuring capacity and capacity utilization in fisheries. FAO Fisheries Technical Report No. 386. Food and Agriculture Organization of the United Nations, Rome.

Klein, L.R., Long, V., 1973. Capacity utilization: concept, measurement, and recent estimates. Brookings Papers on Economic Activity 3, 743–756.

Klein, L.R., Summers, R., 1966. The Wharton index of capacity utilization. Studies in Quantitative Economics, University of Pennsylvania, Philadelphia, PA, 94 pp.

Kmenta, J., 1971. Elements of Econometrics. Macmillan Publishing Co., Inc., New York.

Koopmans, T., 1951. An analysis of production as an efficient combination of activities. In: Koopmans, T. (Ed.), Activity Analysis of Production and Allocation. Cowles Commission for Research in Economics, Monograph No. 13. Wiley, New York.

McFadden, D., 1978. Cost, revenue, and profit functions. In: Fuss, M., McFadden, D. (Eds.), Production Economics: A Dual Approach to Theory and Applications, Vol. I. North Holland, Amsterdam, pp. 2–109.

Morrison, C.J., 1985. primal and dual capacity utilization: an application to productivity measurement in the US automobile industry. Journal of Business and Economic Statistics 3, 312–324.

National Research Council, 1999. Sharing the fish: toward a national policy on individual fishing quotas. Committee to review Individual Fishing Quotas. Washington, DC, 436 pp.

Nelson, R., 1989. On the measurement of capacity utilization. Journal of Industrial Economics XXXVI, 273–286.

Paul, C.J., Johnston, W., Frengley, G., 2000. Efficiency in New Zealand sheep and beef farming: the impacts of regulatory reform. Review of Economics and Statistics LXXXII, 325–337.

Scott, A.D., Neher, P.A., 1981. The public regulation of commercial fisheries in Canada. Economic Council of Canada, Ottawa.

Segerson, K., Squires, D., 1990. On the measurement of economic capacity utilization for multi-product industries. Journal of Econometrics 44, 347–361.

Squires, D., 1992. Productivity measurement in common property resource industries: an application to the pacific coast trawl fishery. RAND Journal of Economics 23, 221–236.

Squires, D., Jeon, Y., Grafton, R.Q., Kirkley, J., 1999. Fishing capacity and individual transferable quotas in the British Columbia halibut longline fishery, Mimeo.