Controlling excess capacity in common-pool resource industries: the transition from input to output controls*

Dale Squires, Yongil Jeon, R. Quentin Grafton and James Kirkley[†]

Overcapacity is a major problem in common-pool resources. Regulators increasingly turn from limited entry to individual transferable use rights to address overcapacity. Using individual vessel data from before and after the introduction of individual harvest rights into a fishery, the paper investigates how characteristics of rights, scale of operations and transition period affect changes in individual and fleet capacity utilisation and excess capacity. The results indicate that individual harvest rights in both theory and practice offer the potential to address the problem of overcapacity in common-pool resources currently managed with limited-entry regulations.

Key words: common-pool resources, limited entry, overcapacity, property rights.

1. Introduction

Overcapacity is a well-known problem with the exploitation of common-pool resources. For example, firms may wish to invest in inputs to ensure that they can secure a minimum viable level of production from the scarce resource.[1] Such investments are individually rational provided that the benefits of the investment outweigh the associated costs, but for the industry as a whole they are wasteful because they simply redistribute the scarce output or

[1] The emphasis in some common-pool resources, such as fisheries, is frequently on overcapitalisation. Overcapitalisation, however, entails only excessive amounts of the capital stock and overlooks other potential stock resources such as labour (which is sometimes variable and sometimes fixed) and variable inputs. Hence, the emphasis on overcapitalisation overlooks the entire bundle of inputs that are excessively allocated to the sector.

yield between firms without increasing overall output or revenues. Over-capacity also raises the potential – and sometimes the actual – exploitation rate of the resource stock, which itself may well be overexploited.[2] By raising their debt load, overcapacity makes firms more vulnerable to changes in the resource base, regulations, environmental conditions and prices. Excess capacity may also make it difficult for the regulator to reduce the total yield in response to declines in the resource stock without imposing bankruptcies and job losses, or lead to negative spillovers in other industries and resources.

To overcome overcapacity, regulators increasingly use output controls, and especially transferable property rights, rather than input controls. Transferable harvest rights for individual fishing vessels are commonly called individual transferable quotas (ITQs) and give firms a fixed share of the total allowable catch (TAC).[3] If harvesting rights are well-defined and transferable, there are no transaction costs and with sufficient time, firms can either exit or trade to a desired level of capacity utilisation. Thus, ITQs can potentially prevent further increases in overcapacity in fisheries that would occur in limited-entry fisheries with input controls and offer the possibility of increased capacity utilisation for those firms that remain fishing and purchase ITQs to achieve a desirable scale of production.

Despite the growing use of ITQs in fisheries and the worldwide problem of overcapacity in fisheries, only Dupont *et al.* (2002) tested for changes in capacity immediately following the introduction of transferable harvesting rights. Only a limited number of studies have tested for the changes in capacity using data from before, at the time of introduction, and some years after the implementation of ITQs.[4] Such analysis is required to assess whether the benefits of ITQs to reduce excess capacity and raise capacity utilisation have, in fact, been realised. Thus, our paper helps shed light on the following questions: how rapidly does adjustment in capacity utilisation occur with the introduction of individual harvesting rights? Do differences in the characteristics of the property rights (especially transferability) have an impact on the capacity changes? To what extent does the existing level of capacity of firms influence changes in capacity and CU over time? Using individual firm data

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[2] This is particularly true of fisheries not regulated with a TAC but instead are controlled by a limited opening. For example, in escapement fisheries like salmon fisheries, fishers are permitted to fish only at very restricted periods so as to allow sufficient fish to escape up river to spawn. The greater the fishing capacity, the more difficult it is for the regulator to estimate the timing of the 'opening' to fish, and the greater the likelihood that more fish will be harvested that is desired from a biological perspective.

[3] Like our paper, Asche *et al.* (2009), by distinguishing between nontransferable and transferable quotas, discuss the importance of transferability for capacity adjustment. They analyse a fishery with individual but not transferable quotas, indicating that the corrected incentives using individual quotas do not improve their situation, as the main challenge is the capacity, which is only reduced with transferability. Also, Homans and Wilen (2005) discuss the important feature of changes in fishing practices that increase revenue rather than improve capacity utilisation although this is not directly relevant in using a primal approach like our paper.

[4] The recent literature on estimating the change in the CU in fisheries includes Felthoven (2002), Weninger (2008), Lian *et al.* (2008) and Weninger (1998).

from the British Columbia halibut fishery from before and after the introduction of ITQs, the paper addresses each of these questions by providing individual and fleet capacity and CU measures and testing for changes in these measures over time and across vessel size (Homans and Wilen 1997).

Section 2 reviews the notions of capacity and CU, in renewable common-pool resource industries with stock-flow production technologies. Section 3 describes the BC halibut fishery that was in the transition phase. Section 4 tests for changes in capacity and CU from before and after the introduction of ITQs. Section 5 discusses the empirical results at the level of the individual firm and for the industry, while Section 6 concludes.

2. Capacity and capacity utilisation and common-pool resources

Traditional measures of capacity and CU are primal measures and are based on the notion of sustainable maximum possible output given the fixed factors, where variable inputs are fully utilised under normal operating conditions (Morrison 1985; Corrado and Mattey 1997).[5] Johansen (1968) was one of the first to develop a primal measure of capacity, which was later extended by Färe *et al.* (1989). Primal measures of capacity correspond to the full-input point on a production function, provided that it is sustainable (Klein and Long 1973).[6] CU is usually defined as the ratio of actual output to some measure of potential output (Morrison 1985; Nelson 1989). Thus, a CU value less than unity implies that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers 1966).

In common-pool resource industries, firms face at least two factors or stocks that affect their capacity – the resource stock and the stock of capital. Measures of capacity and capacity utilisation then face the unique issue of accounting for the resource stock because the greater the stock, and hence

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[5] Morrison (1993) and Corrado and Mattey (1997) discuss the definition of full employment or full utilisation level of variable inputs. They note that it depends upon the type of technology and institutional factors that constitute issues such as 'normal' downtime. Short-run output varies with technology type in different ways according to (i) duration and (ii) intensity or speed of operations. Duration, rather than intensity, is generally more important in fishing industries, because the biological conditions (e.g. species type) tend to dictate speed of operations such as tow speed or encircling rates or 'soak' time in the water for passive line or net gear. Intensity plays a larger role in defining full utilisation of the variable inputs, to the extent that on-board processing constrains intensity.

[6] Klein and Long (1973, p. 744) state that, 'Full capacity should be defined as an attainable level of output that can be reached under normal input conditions – without lengthening accepted working weeks, and allowing for usual vacations and for normal maintenance.' Garofalo and Malhotra (1997) observe that the U.S. Bureau of the Census survey uses the concept of practical capacity, defined as 'the maximum level of production that this establishment could reasonably expect to obtain using a realistic employee work schedule with the machinery and equipment in place' and assuming a normal product mix and downtime for maintenance, repair and cleanup. Both Klein and Long and Garofalo and Malhotra discuss the dependence of full capacity upon 'normal operating conditions'. Normal operating conditions, in turn, are implicitly dependent upon the structure of property rights and the associated institutions.

surplus yield or flow of overall output, the higher the CU of firms for a given stock of capital or other fixed factors. Capacity measures are thus contingent on the level of both the resource stock and the firms' capital stocks. To account for this phenomenon, a technological economic measure of capacity can be defined as the maximum yield in a given period of time that can be produced given the current technology, state of the resource and environmental parameters while keeping fixed factors at their current level and with the unrestricted use of the variable inputs under normal operating conditions.[7]

An important issue when measuring capacity in common-pool resource industries is that the resource stock must either not decline over time or always remain above a minimum viable level. This sustainability requires that the industry's overall output flow not exceed a sustainable target yield, such as maximum sustainable yield, and maintain the resource stock at a corresponding sustainable target level.[8] Thus, from the perspective of the technological economic primal approach, industry excess capacity exists whenever industry capacity output exceeds the target sustainable level of industry output, the latter as defined by a sustainable TAC (FAO 1998, 2000; Kirkley and Squires 1999). By contrast, in other industries that do not exploit a common-pool resource stock, excess capacity is defined as the level of capacity output for an individual firm in excess of current output.

3. Capacity and the British Columbia halibut fishery

The BC halibut fishery, prior to the introduction of ITQs, limited entry with input controls. Strict limits were placed on the minimum fish size that can be harvested for biological reasons, and a total harvesting limit ensured a sustainable exploitable biomass. Over time, increasing restrictions were placed on eligibility to fish for halibut in Canadian waters. Because of protests and appeals by BC fishers, licences were allocated even to fishers without significant association in the fishery. Thus, a total of 435 halibut vessel licences were allocated in 1979, despite only about active 300 vessels.

The restriction on vessel entry failed to prevent increased fishing effort of those vessels already in the fishery. Vessel length and gear restrictions were

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[7] Specification of the resource stock as a technological constraint rather than as a natural capital stock under the control of an individual firm circumvents the indeterminancy problem of capacity and CU with multiple capital stocks under the control of firms. That is, provided there is a single capital stock, specification of the resource stock as a technological constraint does not specify a second capital stock under the control of the firm. This indeterminancy problem is compounded when there are multiple outputs along with multiple capital stocks (Berndt and Fuss 1989).

[8] The target level of output (resource flow) can be a moving target if the target level of output is periodically adjusted, such as when the resource stock is not presently at a long-term optimal level. If the management authority intends to let the resource stock grow, i.e. the resource is in a rebuilding phase, then the sustainable target should be sufficiently small enough to allow growth of the resource stock to exceed depletions from exploitation. The exploitation rate could exceed the target yield if the resource stock is in a drawing down phase starting from high levels of resource abundance.

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

Source: Grafton *et al.* (2000).

subsequently imposed to address the problem, and the season length was systematically reduced over the 1980s due to capture of the TAC in a progressively smaller period of time. Contributing to the problem was the gradual 'take-up' and use of the unused, but allocated, halibut fishing licences such that from 1980 to 1990, the number of active vessels increased by 30 per cent, while the number of fishing days declined by over 90 per cent (Table 1 and Turner and Weninger 2005).

The increase in the number of vessels was also associated with an increase in the number of crew per vessel and duration of fishing per vessel per day. The use of the fishing season as an input control exacerbated the overcapacity problem because it provided an additional incentive, over and above the rivalry associated with catching a scarce TAC, for firms to invest in inputs and catch their desired share of the TAC before the season ended. For example, if fishers have a standardised and fixed catch rate of q per level of fishing effort unit per day, with a fixed TAC and identical fishers, then the smallest aggregate fleet fishing effort needed to catch the total harvest in a limited season of length S is

$$K^* = \frac{\text{TAC}}{qS} \qquad (1)$$

Thus, for a fixed TAC and q, a decrease in the season length increases the minimum total fleet fishing effort and reduces the CU.[9] The end result of a

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[9] This result is adapted from Clark (1990, p. 263), who shows the same outcome in terms of the smallest fleet capable of catching the TAC over the entire season.

decline in the fishing season in the fishery was that by 1990, it was just 6 days long for each vessel and, by various measures (vessel numbers, variable inputs employed), fishing inputs had substantially increased since the introduction of limited-entry regulations 11 years earlier.

The failure of limited-entry and input controls to prevent further 'effort creep' led a group of fishers to request that the regulator introduce a system of ITQs. The fishers initiating this request believed that a switch to individual output controls would make the season length restriction redundant and allow more profitable fishers to expand their operations by purchasing harvesting rights from the less profitable. Following extensive deliberations and a vote in 1990 in which the majority of fishers voted in favour of introducing ITQs, the new management system was introduced in 1991. ITQs were allocated *gratis* to vessel owners on a formula based on the best catch in the previous 4 years and the vessel size. This allocation tended to favour more marginal fishers, who may have had only one good harvest, and also fishers with larger vessels.

For the 1991 and 1992 seasons, the individual harvest rights were not transferable except when the halibut fishing license and vessel were sold together. Starting in 1993, the harvest rights were made transferable among halibut license holders, although restrictions remained on both the divisibility of the rights and the total amount of rights that any one vessel can have (Casey *et al.* 1995; Grafton *et al.* 2000). Continuing limits on the divisibility of quota have tended to favour larger vessels that have the scale of operations to buy quota in larger quantities, and quota trading has tended to increase the average size of vessels.

Introduction of ITQs in 1991 also rendered the season length restriction redundant as a method to control total fleet harvest. Thus, the season length increased dramatically from just 6 days in 1990 to 214 days in 1991 and subsequently to 245 days. However, restrictions remain on the gear that can be used to catch halibut and vessel length restrictions attached to the halibut license and other species licenses in BC.

4. Testing for changes in capacity and capacity utilisation

Individual vessel data from the BC halibut fishery offer a unique opportunity to measure capacity output and CU before and after the introduction of individual harvesting rights. Data are available from 44 vessels in 1988 when the fishery was under limited-entry regulations, from 44 vessels in 1991 when individual harvesting rights were first introduced, and from 19 vessels in 1994, 3 years after the introduction of individual output controls and a year after the harvesting rights were made transferable and more divisible. Unfortunately, the data are not from a panel of vessels but are from randomly selected cross sections of vessels in all three periods. The mean and standard deviation of the revenue, harvests and costs of the sample fishers, in all three periods, are provided in Table 2.

Table 2 Summary statistics of the data

Variable	1988, 1991, 1994		1988	
	Mean	Std. Dev.	Mean	St. Dev
Vessel length (metres)	14.10	5.45	14.48	3.54
Crew weeks	12.91	9.68	15.68	11.33
Fuel quantity (litres)	6995.15	9505.11	8303.38	13 201.26
Halibut revenue	88 747.81	70 140.23	107 329.48	74 208.75
Price of halibut	2.78	0.72	2.03	0.15
Halibut landings (pounds)	34 026.63	28 966.98	51 769.55	33 978.76
Crew	3.78	1.48	4.52	1.55
Weeks fished	3.36	1.92	3.39	1.97
Landings/crew	8143.52	4561.69	10 735.89	4863.64
Landings/week	11 731.65	9798.18	17 541.05	11 388.93
Fuel cost	2420.62	3634.45	3257.05	5137.61
Labour cost	2081.87	740.22	2346.55	767.18
No. observations	107		44	
	1991		1994	
Vessel length (metres)	13.44	7.34	14.73	3.77
Crew weeks	8.57	5.39	16.53	9.85
Fuel quantity (litres)	4153.69	2767.51	10 545.78	7758.94
Revenue	51 378.07	34 241.58	132 257.05	82 213.02
Price	3.08	0.21	3.85	0.30
Halibut landings (pounds)	16 475.10	10 690.77	33 583.47	19 681.81
Crew	3.02	1.09	3.79	1.28
Weeks fished	2.91	1.79	4.37	1.74
Landings/crew	5224.56	1972.49	8682.33	4283.86
Landings/week	7199.40	5809.97	8653.84	6131.51
Fuel cost	1122.86	710.79	3488.95	2548.30
Labour cost	1745.87	590.17	2247.05	715.96
No. observations	44		19	

Notes: All values are in 1994 Canadian dollars and are per vessel. Crew size includes captain. Weeks fished pertain to weeks actively fishing halibut. Halibut landings are in pounds, and the price is per pound. Fuel quantity is in litres and vessel length in metres.
Source: Grafton *et al*. (2000).

The data for the 107 observations were used to solve the output-oriented data envelopment analysis (DEA) of Färe *et al*. (1989), which is specified in Appendix I. The DEA model specifies output as the round weight of halibut landed (pounds) per vessel per day fished and the vessel's capital stock and fixed input is measured by its gross registered tonnage. Capacity output in the stock-flow production technology of a natural resource industry is conditional upon the natural resource stock. Thus, halibut biomass (tons) is also included as a fixed variable and is divided by the number of days fished for each vessel to be consistent with the specification of output on a daily basis.

The excess capacity measures are conditional on the duration of the fishing season and number of vessels, given the resource stock size and availability. Any meaningful comparison over time therefore requires a standardised metric, which is provided by the capacity output measure per vessel per day

of operation.[10] A daily measure of vessel capacity output allows for the full utilisation of the variable inputs and accounts for the differences in season length before and after the introduction of ITQs. Daily measures may be extrapolated to an annual basis for each vessel by multiplying the capacity output per vessel per day of operation by the number of days in the halibut season. Measuring capacity output on a daily production basis thus solves the problem of a varying annual production period because of the regulations in fishing industries. Duration of the fishing season also helps to establish the prevailing normal operating conditions, such that multiplying this measure by the number of vessels in the fleet gives annual industry capacity.[11]

A second-stage analysis evaluated the vessel-and-per-day effects of ITQs on the fleet by regressing capacity output and CU per vessel per day upon dummy variables for year and vessel size classes.[12] The explanatory variables in these regressions 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 vessel length: small, or less than 1400 cm (D_S) and large, equal to or greater than 1400 cm (D_L). Tobit regressions accounted for the censoring of the CU measures at zero and one when CU was the dependent variable (CU ranges between 0 and 1 inclusive). Ordinary least squares were used when capacity output was the dependent variable.

Using the second-stage regression results, the effects of transferable property rights were evaluated by tests of the null hypothesis of *no* changes in capacity or CU between the three time periods (1988–1991, 1991–1994 and 1988–1994) and for a given vessel size class (large and small). Thus, H_0: D_{88} D_S−D_{91} D_S = 0 tests the null hypothesis of equal capacity or CU for small vessels between 1988 and 1991. *F*-tests were used with the ordinary least squares regressions, but Wald tests were used with the Tobit regressions.

5. Transferable property rights and capacity

Summary measures of the mean halibut capacity output per vessel per operating day over the 3 years 1988, 1991 and 1994, and all years combined are reported in Table 3. Mean capacity per vessel per operating day

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[10] The data preclude us from quantitatively accounting for intensity, because we do not have, for example, the number of hours fished per day or the number of lines with their 'soak' time.

[11] This approach allows capacity to be calculated corresponding to normal operating conditions. Specifying the number of days or vessels and multiplying the capacity per day by the number of days gives the normal operating conditions. Capacity per day could also be multiplied by each vessel group's maximum observed days at sea when calculating the annual capacity measures. Projections for the future are found by multiplying capacity per day by the expected days at sea and number of vessels.

[12] This approach allows us to account properly for the data set as a pooled time series of cross sections rather than as a panel data set, because we evaluate cohorts – vessel size classes – rather than individual vessels over time (Deaton 1995). Specifically, the regression coefficients for each cohort in each time period are sample means for that cohort-time period.

Table 3 Summary statistics of capacity and capacity utilisation per vessel per day

	Capacity			CU		
	All Vessels	Small Vessels	Large Vessels	All Vessels	Small Vessels	Large Vessels
All years 1988–1994						
Mean	92 147	84 239	107 744	0.38	0.32	0.51
Median	97 883	93 549	112 309	0.33	0.21	0.51
Maximum	162 100	125 296	162 100	1.00	1.00	1.00
Minimum	7881	7881	47 353	0.06	0.06	0.07
Std. Dev.	32 421	30 780	30 193	0.27	0.27	0.25
Observations	107	71	36	107	71	36
Year 1988						
Mean	111 408	103 581	121 706	0.47	0.40	0.55
Median	114 167	108 411	124 651	0.47	0.41	0.58
Maximum	162 100	125 296	162 100	1.00	1.00	1.00
Minimum	19 874	19 874	47 353	0.06	0.06	0.07
Std. Dev.	27 331	24 983	27 481	0.26	0.26	0.24
Observations	44	25	19	44	25	19
Year 1991						
Mean	84 703	79 534	102 278	0.23	0.20	0.31
Median	87 093	87 093	99 245	0.17	0.16	0.35
Maximum	136 984	120 608	136 984	1.00	1.00	0.47
Minimum	7881	7881	66 076	0.06	0.06	0.12
Std. Dev.	30 616	29 894	27 526	0.18	0.18	0.12
Observations	44	34	10	44	34	10
Year 1994						
Mean	64 782	57 273	77 654	0.55	0.47	0.68
Median	69 371	58 147	82 664	0.51	0.37	0.70
Maximum	90 654	79 101	90 654	1.00	1.00	0.95
Minimum	31 082	31 082	54 637	0.07	0.07	0.27
Std. Dev.	18 263	16 556	13 856	0.32	0.34	0.23
Observations	19	12	7	19	12	7

Note: Small vessels ≤1400 cm length. Large vessels > 1400 cm length.

over all three periods combined was 92 147 pounds, and the mean CU per vessel was 0.38. Mean daily capacity output and CU were both higher for large vessels compared to small vessels over all 3 years combined, and for each individual year.

The results indicate that all vessels did not fully utilise their daily capacity, but this effect is emphasised for smaller vessels. For 1991, this difference was, in part, accentuated because the initial allocation of harvesting rights tended to favour larger vessels. Table 3 also indicates that capacity output declined for both small and large vessels from 1988 to 1991, and again from 1991 to 1994, and over the entire period from 1988 to 1994. By contrast, CU first dipped and then rose for all vessels taken together, and separately for both small and large vessels.

Second-stage regression analysis can be used to test the null hypotheses of *no change* in capacity output and CU per vessel per operating day for

all vessels, and for small and large vessels separately, over the three periods 1988–1991, 1991–1994 and 1988–1994. The estimates of the coefficients of the dummy variables are the mean values for the defined subgroups – vessels and years – given in Table 4. All coefficients are significant at the 5 per cent level, with the exception of the coefficient D_{91} for small vessels. Table 5 reports the detailed hypothesis test results. Table 6 summarises the results of the hypothesis tests and whether daily vessel capacity catch

Table 4   Second-stage regression results

Dummy variable for	Tobit regression for capacity utilisation	OLS regression for capacity output
1988 small vessels		
Coeff	0.422	103 581.10
t-stat	41.774	19.81
1991 small vessels		
Coeff	0.077	79 534.04
t-stat	1.606	17.74
1994 small vessels		
Coeff	0.255	57 272.92
t-stat	2.454	7.59
1988 large vessels		
Coeff	0.557	121 706.40
t-stat	21.335	20.29
1991 large vessels		
Coeff	0.401	102 278.20
t-stat	27.292	12.37
1994 large vessels		
Coeff	0.736	77 654.19
t-stat	7.001	7.86
Log-likelihood		
	43.006	−1237.09

Notes: All variables are dummy variables. The estimates were obtained using the Berndt–Hall–Hall–Hausman maximisation algorithm.

Table 5   Tests of significance for changes in daily vessel capacity output and capacity utilisation over time and by vessel size class

Null hypotheses	Capacity per vessel per day		Capacity utilisation per vessel per day	
	Test statistic	Significance	Test statistic	Significance
1988 Small = 1991 Small	12.18	0.00	36.99	0.00
1988 Large = 1991 Large	3.62	0.06	19.66	0.00
1991 Small = 1994 Small	6.43	0.01	3.73	0.06
1991 Large = 1994 Large	3.65	0.06	9.61	0.00
1988 Small = 1994 Small	25.43	0.00	2.33	0.13
1988 Large = 1994 Large	14.52	0.00	2.92	0.09

Notes: 1. Hypothesis tests for capacity output per vessel per day are *F*-tests with one degree of freedom. 2. Hypothesis tests for capacity utilisation are Wald tests with one degree of freedom.

Table 6 Percentage change and significance of daily vessel capacity and capacity utilisation changes over time and by vessel size class

Capacity and capacity utilisation	Small vessels			Large vessels		
	1988–1991	1991–1994	1988–1994	1988–1991	1991–1994	1988–1994
Capacity per vessel per day	−23.2*	−28.0*	−44.7*	−16.0*	−24.1	−36.2*
Capacity utilisation per vessel per day	−81.8*	+231.2	−39.6	−28.0*	+83.5*	+32.1

*Statistically significant at the 5 per cent level.

and CU increased or decreased and whether the change was statistically significant.

Table 6 indicates that capacity output per vessel per operating day for both small and large vessels significantly declined between 1988 and 1991, falling by 23 per cent for small vessels and 16 per cent for large vessels. The significant decline in daily vessel capacity output for small vessels continued over the period 1991 to 1994, falling by a further 28 per cent. Although daily capacity catch per vessel also fell for large vessels from 1991 to 1994, the decline was significant at the 6 per cent level. Over the entire period 1988 to 1994, daily vessel capacity catch fell significantly for small vessels by 45 per cent and fell by 36 per cent for large vessels. Daily vessel CU for small vessels significantly declined at the 1 per cent level over the period from 1988 to 1991 and at the 6 per cent level for the period from 1991 to 1994 but did not significantly change for the period from 1988 to 1994. Such a decline is attributable, in part, to the initial allocation of harvesting rights favouring larger vessels and because of the 44 per cent decline in TAC from 1988 to 1991. For large vessels, daily vessel CU declined at 1 per cent level of significance from 1988 to 1991, increased at 1 per cent from 1991 to 1994, and increased at 10 per cent over 1988–1994.

In sum, over the entire time period, the introduction of individual harvest rights was associated with a decline in production capacity per vessel per operating day for both vessel size classes. Moreover, the introduction of individual harvest rights coincided with a significant increase in CU per vessel per operating day for large vessels from 1991 to 1994. In part, the higher CU for large vessels may be explained by their favourable treatment in the initial allocation of quota in 1991. In addition, a larger scale of operations likely gives larger vessels greater flexibility to adjust their capacity, especially in terms of variable inputs like labour.

5.1 Explaining changes in capacity and capacity utilisation per vessel per day: 1988–1991

Capacity output per vessel per operating day for both small and large vessels fell because of both reduced crew size (Table 2) and a reduced duration of the

fishing day or trip. This occurred because the frenzied production rate under the limited-entry fishery no longer existed with the 15-fold increase in the fishing season from 1988 to 1991. An important factor in the unexpected decline in CU per vessel per operating day from 1988 to 1991 was the 44 per cent drop in the TAC – the sustainable target industry output – from 5833 to 3261 metric tons. This almost 50 per cent decline in the total permitted sustainable output forced both small and large vessels to harvest much less than they wished.

Another important explanation for the lack of increase in CU between 1988 and 1991 is that individual harvest rights were not transferable in 1991 or 1992. Thus, firms did not face a market price associated with a marginal change in harvesting and could neither overcome any harvest constraint by purchasing quota nor increase their fishing effort to compensate for the decline in the TAC because the individual output controls were fully enforced by the regulator. In other words, individual output controls without transferability, combined with a large decline in the TAC and a removal of season length constraint reduced the CU per operating day of vessels. The net result was that CU per vessel per day of production declined, despite the fact that capacity fell over the period.

5.2 Explaining changes in capacity and capacity utilisation per vessel per day: 1991–1994

Beginning in 1993, individual harvest rights have been transferable among the 435 fishers with a halibut fishing licence. Transferability has allowed some vessels to expand their scale of operations by buying quota from exiting vessels. Thus, trading has enabled some firms to exit and others to accumulate quota, increasing the scale of their operations and thereby matching quota holdings to capacity output. Overall quota trading increased the concentration of individual harvest rights with firms having larger vessels. As a result, the number of active vessels in the industry fell from close to its maximum level of 433 in 1991 to 313 in 1994, a decline of about 28 per cent. Vessel numbers continued to decline as vessels consolidated their holdings of harvesting rights, and by 1996 there were only 282 vessels operating in the fishery.

Transferability of the harvest rights also permitted excess capacity to exit the fishery and allowed firms that have remained in the industry to increase their capacity utilisation. Thus, for both small and large vessels, mean capacity catch per vessel per operating day fell and CU per vessel per operating day increased over the 1991–1994 period. However, the only statistically significant changes were the declines in capacity output per vessel per operating day for small vessels and the increases in CU per vessel per operating day for large vessels.

An almost 50 per cent increase in the TAC from 1991 to 1994 combined with a decline in the number of active vessels has contributed to a doubling of

the mean landings of sample fishers over the period. Thus, a higher output per vessel because of both a larger TAC and quota accumulation, coupled with a declining or stable capacity output per vessel per operating day, contributed to the 83 per cent increase in the mean CU per vessel per operating day for large vessels over the period 1991–1994 (Table 4). These combined changes contributed to the 37 per cent decline in industry capacity and excess capacity over the same period.

Overall, the results support the theoretical predictions that the introduction of individual and *transferable* harvesting rights into a limited-entry and input-controlled fishery should result in an overall decline in excess capacity. The results also emphasise the importance of transferability of the harvesting rights in helping to reduce excess capacity.

6. Concluding remarks

Common-pool resources under open access have long suffered from excess capacity because output is rivalrous, such that investments in increased capacity at a firm level may be profitable, but at the industry level, they fail to increase the total yield that is fixed by nature. In fact, such increases in industry capacity often tend to place additional harvest pressures on the resource stock. The traditional method of controlling this problem has been to restrict the number of harvesters and control their inputs. Limited-entry regulations have often been unsuccessful at preventing ongoing increases in excess capacity because firms are frequently able to substitute from regulated to unregulated inputs (Dupont 1991; Squires 1994). Consequently, in some common-pool industries with ill-structured property rights, such as fisheries, substantial excess capacity exists.

To help address the excess capacity and rent dissipation problem in open-access fisheries, regulators are increasingly using individual output controls in the form of individual and transferable harvest rights. Using data from the BC halibut fishery before and after the introduction of individual harvest rights, measures of capacity output, excess capacity and capacity utilisation are calculated. The results indicate that the introduction of individual and transferable harvest rights has coincided with substantial and statistically significant reductions in capacity output. The results also indicate that median capacity utilisation is higher for large versus small vessels both before and after the introduction of harvesting rights.

Capacity in the fishery declined, in part, because the switch to individual harvesting rights allowed a change in season length from 6 days to 214 days, and subsequently to 245 days. The much longer fishing season reduced the previously hectic pace of fishing and allowed firms to substitute some variable inputs with increased time at sea. Another important contributing factor to the reduced excess capacity has been the transferability of individual harvest rights that has created an opportunity cost from harvesting, allowed firms to

exit the fishery and remove their capacity, and permitted remaining firms to expand their output to achieve a better scale of production. Overall, the empirical results confirm our theoretical insight that individual and transferable harvest rights, given sufficient time, and relative to limited-entry regulations, are able to reduce excess capacity and increase firm capacity utilisation.

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Appendix I

Measuring capacity using data envelopment analysis

The nonparametric DEA approach proposed by Färe (1984) and Färe *et al.* (1989) estimates capacity output given the capacity base, resource stock and environmental conditions. Capacity output corresponds to the output that could be produced, given full and efficient utilisation of variable inputs under normal operating conditions, and given the constraints imposed by the fixed factors, the state of technology and resource stock. Firms do not produce at full capacity if they are technically inefficient or employ insufficient levels of variable inputs given the constraints. Different levels of the resource stock would yield different levels of capacity in the stock-flow production technology of a common-pool resource industry, such as a fishery.

Following Färe *et al.* (1989), we define $j = 1, \ldots, J$ observations or firms in an industry producing M outputs, $\mu \in R_+^M$, by using a vector of inputs $x_j \in R_+^N$, where R_+^M and R_+^N are sets of all non-negative real numbers, and N is partitioned into fixed, F_x, and variable inputs, V_x. μ_{jm} denotes the mth output

produced by the jth firm and x_{jn} denotes the utilisation of the nth input by the jth firm. Inputs and outputs satisfy the following assumptions:

(i) $u_{jm} \geq 0,\ x_{jn} \geq 0$

(ii) $\sum_{j=1}^{J} u_{jm} > 0,\ m = 1, 2, \ldots, M$

(iii) $\sum_{n=1}^{N} x_{jn} > 0,\ j = 1, 2, \ldots, J$

(iv) $\sum_{j=1}^{J} x_{jn} > 0,\ n = 1, 2, \ldots, N$

(v) $\sum_{m=1}^{M} u_{jm} > 0,\ j = 1, 2, \ldots, J$

Condition (i) imposes the assumption that each producer uses non-negative amounts of each input to produce non-negative amounts of each output. Conditions (ii) and (iii) require total or aggregate production of positive amounts of every output and total or aggregate employment of positive amounts of every input. Conditions (iv) and (v) require that each firm employs a positive amount of at least one input to produce a positive amount of at least one output. Zero levels are permitted for some inputs and outputs.

Färe *et al.* (1989) illustrate that capacity at the plant level, following Johansen (1968), could be estimated by partitioning the fixed (F_x) and variable inputs (V_x) and solving the following output-oriented, DEA problem:

$$\max_{\theta, z, \lambda} \theta \tag{2}$$

subject to:

$$\theta u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm},\ m = 1, \ldots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn},\ n \in F_x$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn},\ n \in V_x$$

$$z_j \geq 0,\ j = 1, 2, \ldots, J$$

$$\lambda_{jn} \geq 0,$$

where θ is an output-oriented measure of technical efficiency ($\theta \geq 1.0$), and z_j is the intensity variable for the jth observation (which serves to construct the

technology by taking convex combinations of the data).[13] Multiplying the observed output by θ gives an estimate of capacity output.[14] Capacity can also be estimated by solving problem (2) without the variable input constraints. Problem (2) imposes a strong disposability in outputs and constant returns to scale.[15] Variable returns to scale are introduced by the convexity constraint $\sum z_j = 1$.

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[13] The intensity vector $Z = (Z_1, Z_2, ..., Z_J) \in R_+^J$ denotes the intensity levels at which each of the J firms or producers operate. The Z vector allows a decrease or increase of observed production activities (input and output levels) to construct unobserved but feasible activities. The Z vector provides weights that are used to construct the linear segments of the piecewise, linear technology (i.e. the reference technology constructed by DEA).

[14] Technical efficiency from an output orientation indicates the maximum potential levels by which all outputs could be increased with no change in input levels. A technical efficiency score of 1.0 indicates technical efficiency. The value of θ is restricted to ≥ 1.0. If $\theta > 1.0$, production is inefficient and output levels could be increased by $\theta - 1.0$. θ is the inverse of an output distance function and equals the ratio of the maximum potential output to the observed output level. The expansion in output levels is radial, so that output levels are kept in fixed proportions. Multiplying the observed output by θ gives the estimate of capacity output.

[15] Estimating capacity without the variable input constraints indicates that the variable inputs are in fact decision variables, in line with the Johansen definition that assumes input fixity combined with unlimited access to the variable input dimensions. In addition, strong disposability of outputs implies that the producer has the ability to dispose of unwanted outputs with no private costs.