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Capacity reduction, quota trading and productivity: the case of a fishery*

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We present the first *ex post* study that quantitatively analyses the effects of a licence buy-back and enhanced quota trading on the profitability and productivity of individual vessels in a fishery. Using firm-level data and a profit index decomposition method, we find that small and large vessels and three different trawler fleets all experienced substantial productivity gains in the year immediately following a licence buy-back and the establishment of a quota brokerage service. The apparent ongoing benefits of the buy-back and increased quota trading over the sample period are in stark contrast to the generally unfavourable long-term outcomes commonly associated with vessel buy-backs in input-controlled fisheries.

Key words: capacity reduction, fishery, productivity, quota trading.

1. Introduction

Many fisheries suffer from excess capacity (Kirkley *et al*. 2002) despite the use of input controls and limits on the total number of vessels. The consequences of excess capacity include increased harvesting pressure on fish stocks and an inefficient allocation of resources. A common approach of regulators in input-controlled fisheries is to temporarily address the problem of overcapitalisation with a buy-back of vessels, gear, and/or licences so as to reduce aggregate fishing effort.

Typically, buy-backs are funded out of general revenues, and when buy-backs are voluntary, the less technically efficient vessels predominate in terms of the fishing capacity removed (Pascoe and Coglan 2002). Despite their use in fisheries in Canada, the USA, the European Union, Japan, Taiwan, Norway, and Australia (Holland *et al*. 1999), and costing millions of dollars,

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until now there has been no *ex post* firm-level study that quantitatively analyses the effects of a buy-back on the profits and productivity of the vessels remaining in a fishery. Using a unique data set from the South-east Trawl Fishery (SETF) of Australia, we decompose profits into contributions due to productivity, output prices, input prices, and (quasi-) fixed inputs. The decomposition allows us to assess individual vessel economic performance following a 1997 licence buy-back and the establishment of a brokerage service to stimulate quota trading.

In the following section, we describe the SETF along with details of the buy-back program and the brokerage service. Section 3 outlines the general method used to analyse firm-level economic performance, whereas Section 4 describes the decomposition approach for the particular fishery. Section 5 provides an assessment of the impacts of the licence buy-back and the establishment of a brokerage service on economic performance by vessel size and gear type. The paper concludes with a review of the results and their implications for improving productivity in fisheries that suffer from overcapacity.

2. Australia's South-east Trawl Fishery

The SETF is located in Australia's 200-nautical-mile exclusive economic zone (EEZ). It stretches over a very large area of ocean from south of Sydney to encompass all of Australia's oceans off the coasts of Victoria and Tasmania until just beyond the eastern border of South Australia. The fishery is one of Australia's oldest and is managed by the Australian Fisheries Management Authority (AFMA). The fishery's 100 or so vessels use trawls (otter board, Danish seine, and mid-water trawl) and land over 100 different types of species. Overall, the SETF accounts for about one-fifth of the landed value of the Australian Commonwealth fisheries, or over $A70 million in 1999–2000.

In the past two decades, participants in the fishery have increased their vessel size and capacity. In part, these investments have been made to access deeper water and further offshore fisheries, such as the orange roughy, but they have also occurred as a result of the 'race to fish'. Because of concerns about overcapitalisation, input controls, including restrictions on boat and engine size, were introduced in 1986 but these failed to prevent an increase in the capital employed in the fishery. To help prevent further increases in capacity, AFMA introduced individual transferable quotas (ITQs) in 1992 that encompassed 16 of the major commercial species in the fishery. The initial allocation of ITQs was contentious as some fishers considered their allocations as insufficient compensation for their loss of previous fishing entitlements. The introduction of ITQs also failed to bring about the hoped-for reduction in the number of vessels operating in the fishery with very low levels of quota traded in the first 5 years of the ITQ program. Moreover, for most of the ITQ-managed species, the total allowable catch was non-binding over this period (BRS 2002). To address these concerns, an industry-assisted quota brokerage service was established in 1997 that greatly increased the level of lease quota trading relative to the period 1992–1996. As a consequence, average yearly lease quota trades increased by more than 50 per cent to 26 000 tons in the period 1997–2000 compared with the preceding 5 years (Kompas and Che 2005).

Acrimony from the initial allocations, and a concern that ITQs had not delivered the expected benefits to all fishers, led the regulator to also institute a permit or licence buy-back in 1997. The buy-back had a dual purpose: (i) to remedy the acrimony over the initial allocation and its associated uncertainty and litigation; and (ii) to reduce the perceived overcapacity in the fishery. In total, about \$A4 million was spent in the buy-back that included \$A2.35 million of targeted assistance to 18 fishers designed to avoid further legal action over the initial quota allocation. The sum of \$A1.7 million was used to buy back the fishing licences of 27 fishers (AMC Search Ltd. 2000), with seven fishers receiving both a buy-back of their licences and targeted financial assistance.

The licence buy-back removed 14 active licences and 13 dormant or latent licences from the fishery. Overall, the buyout reduced the number of active fishing vessels from 108 to 94 and vessel capital worth approximately \$A7 million (AMC Search Ltd. 2000). The buyout was taken up by vessels that were mainly '. . . small scale with annual turnover of less than \$A1 million' (AMC Search Ltd. 2000, p. 9). The net effect was to increase the expected profitability in the fishery with the value of the boat licence needed to participate in the fishery rising from \$A60 000 to \$A85 000 immediately following the licence retirement.

We analyse the economic impact of the vessel buy-back and the brokerage service on the economic performance of fishers as a 'natural experiment'. Surprisingly, given the many millions of dollars spent on reducing vessel capacity in fisheries worldwide, our study is the first ever *ex post* analysis of such a program, coupled with the effects of quota trading, on individual vessel-level productivity performance.

3. Method for decomposing firm-level profits

The approach used to decompose relative profits and analyse productivity changes in the SETF is described in detail in Fox *et al.* (2003). It offers important advantages over traditional measures of productivity in fisheries (Squires 1992; Jin *et al.* 2002) in that it provides individual firm-level measures and quantifies the contribution of productivity, inputs, and outputs to relative profits. Thus, it provides an easy way to assess both firm and industry performance at a point in time, and over time.

We briefly review the profit decomposition approach using index numbers. We define the restricted profits of an arbitrary firm b, π^b, relative to the restricted profits of another reference firm a, π^a, by

$$\theta^{a,b} \equiv \frac{\pi^b}{\pi^a} \qquad (1)$$

A productivity index between firms b and a, denoted by $R^{a,b}$, is defined as the ratio of an output index and input index between firms a and b, that is,

$$R^{a,b} \equiv (\theta^{a,b}/P^{a,b})/K^{a,b} \tag{2}$$

where the numerator is an implicit output index (Allen and Diewert 1981), $P^{a,b}$ is a price index of output and variable input prices, where variable inputs are treated as negative outputs and $K^{a,b}$ is a fixed-input quantity index. Productivity defined by Equation (2) is the difference in the output quantity index that cannot be explained by differences in input utilisation. By rearranging Equation (2), we obtain the following profit decomposition,

$$\theta^{a,b} = P^{a,b} \cdot R^{a,b} \cdot K^{a,b} \tag{3}$$

Using Equation (3), the firms' relative profits can be defined in terms of contributions from output prices ($P^{a,b}$), productivity ($R^{a,b}$), and the fixed input ($K^{a,b}$) without making any behavioural assumptions or restrictions on the specific form of the technology used by firms.

To apply the decompositions in the SETF, we first define $p^b = (p_1^b, \ldots, p_M^b)$ as a price vector for vessel b of netput prices specified for M variable netputs, denoted by $y^b = (y_1^b, \ldots, y_M^b)$. In the netput vector, if $y^b > 0$ the good is an output, but if $y^b < 0$, the good is a variable input. The vector of (quasi-) fixed input prices for vessel b is $r^b = (r_1^b, \ldots, r_N^b)$ where there are N fixed inputs, denoted by $k^b = (k_1^b, \ldots, k_N^b)$. Both price vectors satisfy the requirement that each element is positive.

As shown by Fox *et al*. (2003), the Törnqvist (1936) index has a number of useful properties for constructing the price and fixed-input indexes for use in Equation (3).[1] Using the Törnqvist index, $P^{a,b}$ and $K^{a,b}$ in (3) can be denoted as netput price and quantity indexes and are defined by Equations (4) and (5), where $s_m = (p_m y_m)/(\Sigma p_m y_m)$ is the profit share of netput m and $s_n = (r_n k_n)(\Sigma p_m y_m)$ is the profit share of fixed input n:

$$\ln P^{a,b} \equiv \sum_{m=1}^{M} \frac{1}{2} (s_m^b + s_m^a) \ln(p_m^b/p_m^a) \tag{4}$$

$$\ln K^{a,b} \equiv \sum_{n=1}^{N} \frac{1}{2} (s_n^b + s_n^a) \ln(k_n^b/k_n^a) \tag{5}$$

[1] Although Diewert (1992) finds that the Fisher index has a strong justification from both the axiomatic and economic approaches to evaluating index number formulae, the Törnqvist index has a strong justification from the economic approach (Caves *et al*. 1982). In addition, it typically yields results nearly identical to those from the Fisher index, and as will be seen below, it is relatively easy to decompose into contributing components. Unlike the Törnqvist index, the Fisher index does not have an obvious method of decomposition (see, for example, Balk 2004).

The multiplicative nature of the Törnqvist index allows us to decompose the aggregate price and fixed-input indexes between vessels *a* and *b* into a product of individual price and input differences, that is:

$$P^{a,b} = \prod_{m=1}^{M} P_m^{a,b} \tag{6}$$

and

$$K^{a,b} = \prod_{n=1}^{N} K_n^{a,b} \tag{7}$$

where the index for each netput *m* and fixed-input *n* is itself a Törnqvist index. In this manner, Equations (3), (6), and (7) collectively represent a detailed decomposition of profits between firms *a* and *b* (for related index-number decompositions in different contexts, see the seminal paper by Diewert and Morrison (1986) and also Fox *et al*. (2002)). Using these profit decompositions, we can derive individual measures of relative profits over time and the contributions to relative profits from input and output prices, vessel size, and productivity.

4. Profit decompositions and productivity

The profit decomposition method is applied to the SETF using vessel-level data on the implicit output price, fuel price, price for labour, and a capital measure represented by vessel tonnage. The sample data were obtained by the Australian Bureau of Agricultural and Resource Economics (ABARE) and AFMA logbook data, and are an unbalanced panel of 47 vessels over the period 1997–2000, giving a total of 131 observations. Only 17 of the 47 vessels were surveyed in all four periods. Prices are net of general price changes through deflation by the consumer price index. Because of data inconsistencies, 11 observations were dropped, leaving a total of 120 observations to calculate the profit decompositions. Summary statistics are provided in Table 1.

The vessel output price is defined as the total value of landings of all fish divided by the total weight of the fish landed for each vessel, giving a common price per vessel over all species.[2] The (implicit) price for labour is defined as the ratio of total vessel labour payments per vessel over the number of trawling hours and then divided by the number of crew. Thus, the

[2] Using Hicks' aggregation theorem (Hicks 1946, pp. 312–313), if the prices of a group of goods vary in strict proportion, then there exists an aggregate quantity (value divided by the factor of proportionality) over these goods that can be treated as if it were a microeconomic good. Diewert (1978) showed that an approximate version of this aggregation theorem will also hold. That is, as long as prices of species are approximately proportional for each vessel in each period, then we can legitimately use an aggregate quantity over all species. An alternative justification derives from Leontief's aggregation theorem (Leontief 1936), by assuming all quantities vary proportionately. See Diewert (1974) for the implications of aggregation for elasticities of substitution.

Table 1 Summary statistics: data on the South-East Trawl Fishery

	Mean	Std. dev.	Min.	Max.
All years				
Revenue	485 730	453 259	86 110	2 467 011
Landings	229 164	182 048	22 266	1 171 634
Price	2.13	0.71	1.12	4.47
Crew hours	3 562	2 391	128	14 095
Labor price	74	104	15	668
Fuel quantity	1 175	1 135	64	5 312
Fuel price	70.00	6.00	63.00	81.00
Vessel tonnage	82	92	13	670
1997				
Revenue	390 518	378 994	116 996	2 110 863
Landings	215 714	191 165	31 531	1 051 230
Price	1.88	0.69	1.12	4.45
Crew hours	4 129	2 963	1 276	14 095
Labor price	42	24	15	131
Fuel quantity	1 056	1 008	111	4 078
Fuel price	68.00	0.00	68.00	68.00
Vessel tonnage	63	48	13	196
1998				
Revenue	426 822	383 243	86 110	2 094 586
Landings	229 111	205 366	38 389	1 171 634
Price	1.91	0.55	1.22	4.47
Crew hours	3 654	2 404	128	11 829
Labour price	68	99	19	531
Fuel quantity	1 065	1 001	107	4 349
Fuel price	63.00	0.00	63.00	63.00
Vessel tonnage	73	52	13	196
1999				
Revenue	571 656	526 541	98 993	2 467 011
Landings	241 148	181 019	22 266	889 694
Price	2.39	0.77	1.44	4.45
Crew hours	3 197	1 965	360	7 245
Labour price	97	128	16	509
Fuel quantity	1 329	1 296	98	4 521
Fuel price	68.00	0.00	68.00	68.00
Vessel tonnage	94	123	13	670
2000				
Revenue	568 177	510 214	105 770	2 336 295
Landings	231 226	149 968	27 093	615 403
Price	2.38	0.69	1.24	3.90
Crew hours	3 223	2 073	360	7 038
Labour price	93	129	19	668
Fuel quantity	1 274	1 260	64	5 312
Fuel price	81.00	0.00	81.00	81.00
Vessel tonnage	94	124	13	662

Notes: There are 30 observations for 1997, 33 for 1998, 29 for 1999, and 28 for 2000. Landings are in the total volume of fish sold, in kilograms; price is the average price for a kilogram of fish landed; crew hours is the average number of crew times the number of trawling hours; fuel quantity is litres of fuel dispensed; fuel price is the average diesel price for Melbourne; vessel tonnage is gross vessel tonnage (GVT).

measure of productivity is not independent of the crew share that is normally paid as a proportion of a vessel's net revenue. Nevertheless, because the crew share is identical for all vessels and over time, this has no effect on our measures of productivity trends over the 1997–2000 period, although if the opportunity cost of labour changes differentially across vessels it would affect measures of economic profit. Fuel expenditures are recorded for each of the vessels and capital is the vessel gross registered tonnage.

Provided there is only one (quasi-) fixed input, profits are all attributed to the (quasi-) fixed input and s_n, or the share of capital in profit in (5), is unity. Thus, the (quasi-) fixed quantity index defined by (5) reduces to the following,

$$K^{a,b} = \frac{k^b}{k^a} \tag{8}$$

Variable inputs in the fishery are fuel and labour. From Equations (3), (6), and (8), our decomposition of the profit ratio between vessel a and vessel b, where ($b = 1, \ldots, 120$), $\theta^{a,b}$ is given by,

$$\theta^{a,b} = R^{a,b} \cdot PO^{a,b} \cdot PL^{a,b} \cdot PF^{a,b} \cdot K^{a,b} \tag{9}$$

In this profit decomposition, the performance of vessel b relative to vessel a can be decomposed into differences due to productivity ($R^{a,b}$), output ($PO^{a,b}$), variable inputs ($PL^{a,b}$ and $PF^{a,b}$), and vessel capital ($K^{a,b}$).

An important issue to consider is the effect of changes in fish stocks on both profits and productivity. We can account for stock changes by calculating a resource-adjusted measure of efficiency (Fox *et al.* 2003). The stock-adjusted profit decomposition between any arbitrary vessel b and the reference vessel a can be defined by,

$$\theta_s^{a,b} = \theta^{a,b} \cdot \left(\frac{stock^a}{stock^b}\right) \tag{10}$$

where $stock^a$ and $stock^b$ are the values of the overall stock index for reference vessel a and an arbitrary vessel b. Unlike the method proposed by Fox *et al.* (2003), the overall stock index calculated for the SETF is a relative measure of stock abundance and does not consider differences in the total allowable catch over the period.

The overall or aggregate stock index is calculated using nine fish species, that account for at least 70 per cent of the total landed weight and value, and include orange roughy, blue grenadier, tiger flathead, redfish, blue warehou, spotted warehou, school whiting, ling, and gemfish. Appropriate data were not available for the other species. The index was created using a Fisher quantity index, Q_F, which has the following form:

$$Q_F = \sqrt{\left(\frac{p^{t-1} \cdot q^t}{p^{t-1} \cdot q^{t-1}}\right)\left(\frac{p^t \cdot q^t}{p^t \cdot q^{t-1}}\right)} \tag{11}$$

Table 2 Stock indexes

Year	Aggregate	Offshore	Inshore	Danish
1997	1.000	1.000	1.000	1.000
1998	0.874	0.911	0.857	0.922
1999	0.804	0.828	0.797	0.891
2000	0.721	0.751	0.709	0.830

Note: Species in each of the stock indexes reflect the species available to each of the fleets, as follows: 1, offshore = (orange roughy); 2, inshore = (blue grenadier, tiger flathead, redfish, blue warehou, spotted warehou, ling, gemfish); 3, Danish = (tiger flathead, school whiting).

where, using vector notation $p \cdot q = \Sigma_{i=1}^{9} p_i q_i$ for species $i = 1, \ldots, 9$, $t = 1998, \ldots, 2000$ and 1997 is the base period. The term q_i is the official stock assessment for species i and the prices, p_i, are obtained from dividing the total landed value by landed quantities for each species. The calculated overall stock index values over the period are: 1997 = 1.0000, 1998 = 0.8739, 1999 = 0.8036 and 2000 = 0.7214.[3] Thus, the index indicates a decline in overall fish abundance over the period of the study.

Separate stock indexes by vessel can also be calculated, but a stock index for each vessel is problematic because catch differences would not necessarily reflect variations in catchability across vessels. An alternative approach is to construct stock indexes for vessels that employ the same gear and fish in similar locations. In the SETF, there are three main types of vessels: the inshore otter trawlers, offshore otter trawlers, and Danish seine trawlers. We can calculate a separate Fisher quantity index for each fleet that represents only the fish caught by the respective trawler fleets. For example, the offshore trawler fleet only has about half a dozen vessels that almost exclusively catch orange roughy and, thus, the appropriate stock index is based exclusively on that species. Details of the species compositions used to calculate stock indexes for the other two trawler fleets, as well as the overall stock index, is provided in Table 2.

For comparative purposes, a reference firm (a) must be chosen. Using a benchmark that is an observed firm or vessel helps fishers to better assess those factors that are constraining profits that are under their control (such as productivity) from factors that are not (such as fuel prices). This also ensures that the property of transitivity is satisfied, so that all bilateral comparisons between vessels are consistent with one another (see Fox *et al.* 2003). A natural benchmark vessel is one that maximises profit,

[3] Details of the data sources and the total quantity and value of fish landed for each of the 4 years used to calculate the stock index are available upon request. Note that a Fisher index is used here as there is no requirement to decompose the index, see footnote 1 above. Nearly identical results are obtained using a Törnqvist index.

Table 3 Decomposition of profit ratios (θ), 1997

Obs	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	K
1	71 778	0.034	0.047	1.068	0.168	1.024	3.754	0.068
2	45 216	0.021	0.029	0.258	0.128	1.027	6.414	0.136
3	90 379	0.042	0.059	0.077	0.888	1.024	4.874	0.173
4	81 399	0.038	0.053	0.553	0.145	1.025	3.731	0.173
5	115 922	0.054	0.075	0.474	0.217	1.026	4.020	0.178
6	43 087	0.020	0.028	0.006	1.458	1.071	15.825	0.183
7	224 863	0.106	0.146	0.698	0.469	1.029	2.310	0.188
8	113 178	0.053	0.074	0.223	0.263	1.040	6.416	0.188
9	92 302	0.043	0.060	0.284	0.157	1.044	6.467	0.199
10	105 150	0.049	0.068	0.254	0.458	1.043	2.698	0.209
11	59 256	0.028	0.039	0.272	0.160	1.030	4.111	0.209
12	87 345	0.041	0.057	0.529	0.099	1.033	4.796	0.220
13	69 454	0.033	0.045	0.314	0.138	1.037	4.379	0.230
14	234 154	0.110	0.152	0.525	0.328	1.040	3.619	0.235
15	70 882	0.033	0.046	0.095	0.150	1.068	12.362	0.246
16	49 198	0.023	0.032	0.153	0.064	1.084	10.338	0.293
17	52 283	0.025	0.034	0.020	0.091	1.153	51.249	0.314
18	84 178	0.040	0.055	0.220	0.116	1.031	6.659	0.314
19	26 196	0.012	0.017	0.097	0.026	1.106	19.209	0.314
20	77 342	0.036	0.050	0.178	0.107	1.129	6.415	0.366
21	145 141	0.068	0.094	0.471	0.104	1.077	4.907	0.366
22	73 649	0.035	0.048	0.025	0.149	1.162	27.179	0.408
23	216 580	0.102	0.141	0.106	0.417	1.070	6.172	0.481
24	169 132	0.079	0.110	0.182	0.259	1.067	4.194	0.523
25	434 959	0.204	0.283	0.414	0.322	1.059	3.452	0.580
26	284 063	0.133	0.185	0.391	0.233	1.038	2.929	0.669
27	163 996	0.077	0.107	0.126	0.251	1.073	4.170	0.758
28	302 629	0.142	0.197	0.226	0.261	1.068	3.314	0.941
29	380 610	0.179	0.248	0.307	0.191	1.036	4.231	0.962
30	1 325 755	0.622	0.863	1.547	0.371	1.031	1.423	1.025

adjusted for aggregate stock size, relative to all other vessels and over all periods. This corresponds to the vessel denoted by observation 26 in the year 2000.

The profit decompositions are presented in Tables 3 to 6 for the years 1997–2000. Geometric means of the index numbers are given in Table 7 for all vessels and separately for small and large vessels. Table 8 provides a summary of vessel performance in terms of the three trawl fleets. For comparability, the stock-adjusted profit ratios in Tables 3 to 8 are all calculated using the aggregate stock index rather than individual fleet stock indexes. A stock adjustment that uses the separate stock indexes for the three fleets, however, can easily be calculated using the adjustment terms provided in Table 9. For instance, the stock-adjusted profit ratio for each of the three fleets based on their own stock indexes would be calculated by multiplying the values of θ in Table 8 by the appropriate adjustment factor in Table 9 for each year. For example, the 1997 the stock-adjusted profit ratio for offshore vessels using the offshore trawl stock index would be 0.0751 (0.100×0.751)

Table 4 Decomposition of profit ratios (θ), 1998

Obs	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	*K*
1	86 829	0.047	0.057	1.230	0.225	1.031	2.918	0.068
2	16 898	0.009	0.011	0.040	0.154	1.149	14.008	0.110
3	55 508	0.030	0.036	0.180	0.194	1.034	7.356	0.136
4	100 832	0.054	0.066	0.390	0.191	1.031	4.943	0.173
5	94 219	0.051	0.061	0.507	0.208	1.035	3.255	0.173
6	107 753	0.058	0.070	0.429	0.226	1.039	3.920	0.178
7	71 117	0.038	0.046	0.025	1.379	1.068	6.975	0.183
8	249 416	0.134	0.162	0.775	0.449	1.040	2.383	0.188
9	60 510	0.033	0.039	0.134	0.139	1.136	9.893	0.188
10	155 553	0.084	0.101	0.665	0.204	1.044	3.600	0.199
11	108 173	0.058	0.070	0.277	0.362	1.061	3.164	0.209
12	71 802	0.039	0.047	1.406	0.207	1.037	0.741	0.209
13	112 869	0.061	0.073	0.378	0.222	1.035	3.846	0.220
14	94 994	0.051	0.062	0.419	0.205	1.040	3.007	0.230
15	175 170	0.094	0.114	0.392	0.282	1.056	4.151	0.235
16	106 950	0.057	0.070	0.171	0.213	1.078	7.229	0.246
17	105 070	0.056	0.068	0.253	0.200	1.032	5.021	0.261
18	71 132	0.038	0.046	0.229	0.134	1.088	4.722	0.293
19	94 300	0.051	0.061	0.188	0.169	1.038	5.937	0.314
20	42 500	0.023	0.028	0.148	0.079	1.119	6.749	0.314
21	157 209	0.084	0.102	0.299	0.249	1.087	3.463	0.366
22	162 236	0.087	0.106	0.559	0.112	1.099	4.197	0.366
23	124 993	0.067	0.081	0.080	0.353	1.103	6.400	0.408
24	403 648	0.217	0.263	0.593	0.361	1.055	2.499	0.465
25	423 410	0.227	0.276	0.342	0.510	1.054	3.118	0.481
26	299 533	0.161	0.195	0.383	0.296	1.071	3.065	0.523
27	575 114	0.309	0.374	0.500	0.477	1.053	2.565	0.580
28	231 265	0.124	0.151	0.301	0.157	1.126	4.240	0.669
29	158 076	0.085	0.103	0.191	0.147	1.108	4.374	0.758
30	88 383	0.047	0.058	0.013	0.183	1.150	23.732	0.899
31	346 500	0.186	0.226	0.274	0.314	1.070	2.607	0.941
32	525 067	0.282	0.342	0.353	0.288	1.050	3.335	0.962
33	1 242 506	0.668	0.809	2.506	0.299	1.047	1.006	1.025

while using the aggregate stock index, and as given in Table 8, it is 0.0721 (0.100×0.721).

To assist in the evaluation of the decompositions, the pooled index series are plotted in Figure 1, where the observations for each of the 4 years are separated by vertical dotted lines. Figure 1 presents the profit decompositions by observation and by period where vessels in each period are ranked in ascending order based on gross vessel tonnage. When comparing the index values, if an index takes a value greater (less) than one, it contributes by expanding (contracting) the stock-adjusted profit ratio defined by θ_s. For the reference firm, observation 26 in 2000, its index values are unity and the index values for all other firms are relative to this benchmark.

A value of less than one for the output price index indicates that the contribution of the output price to profit is less than in the benchmark firm. Only five observations have a *PO* greater than unity, and most vessels have

Table 5 Decomposition of profit ratios (θ), 1999

Obs	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	*K*
1	94 539	0.055	0.062	0.622	0.521	1.020	2.769	0.067
2	77 596	0.045	0.051	0.178	1.226	1.033	2.070	0.108
3	168 980	0.099	0.110	1.228	0.226	1.019	2.285	0.170
4	157 241	0.092	0.102	0.702	0.365	1.022	2.225	0.176
5	74 587	0.044	0.049	0.122	0.286	1.044	7.356	0.181
6	312 362	0.183	0.203	2.279	0.225	1.082	1.968	0.186
7	175 220	0.102	0.114	0.505	0.356	1.028	3.141	0.196
8	149 319	0.087	0.097	0.671	0.227	1.020	2.878	0.217
9	136 780	0.080	0.089	0.941	0.182	1.018	2.250	0.227
10	137 616	0.080	0.090	0.188	0.560	1.020	3.515	0.238
11	51 511	0.030	0.034	0.052	1.312	1.043	1.941	0.243
12	270 963	0.158	0.176	0.742	0.275	1.058	3.223	0.253
13	161 459	0.094	0.105	0.618	0.195	1.017	3.324	0.258
14	290 947	0.170	0.189	0.533	0.454	1.040	2.696	0.279
15	229 855	0.134	0.150	0.383	0.431	1.044	3.110	0.279
16	78 884	0.046	0.051	0.137	0.311	1.055	3.957	0.289
17	141 379	0.083	0.092	0.335	0.230	1.023	3.756	0.310
18	812 981	0.475	0.529	1.980	0.940	1.023	0.853	0.325
19	115 735	0.068	0.075	0.123	0.234	1.067	6.792	0.362
20	65 522	0.038	0.043	0.033	0.214	1.099	13.370	0.413
21	253 245	0.148	0.165	0.186	0.652	1.042	2.831	0.460
22	185 773	0.109	0.121	0.062	0.377	1.083	10.006	0.475
23	381 622	0.223	0.248	0.815	0.238	1.042	2.377	0.516
24	183 714	0.107	0.120	0.105	0.362	1.085	4.321	0.671
25	654 424	0.382	0.426	0.450	0.674	1.036	1.861	0.728
26	78 805	0.046	0.051	0.017	0.126	1.146	23.231	0.888
27	992 700	0.580	0.646	0.958	0.660	1.037	0.974	1.012
28	333 557	0.195	0.217	0.123	0.429	1.080	2.988	1.278
29	1 437 856	0.840	0.936	0.516	0.601	1.032	0.835	3.502

values considerably less than unity. This suggests that an important factor contributing to the profits of the benchmark vessel are the prices it receives for its harvests. A value greater than one for the input indexes for all vessels does not imply that the input prices are greater than for the benchmark vessel. Rather, it indicates that the contribution of that input price to the profit ratio is greater than for the benchmark vessel. This could arise if the input price for the given vessel is less than that of the reference firm as an increase in the fuel price reduces profits. If the input price for a given vessel is identical to the benchmark vessel, the corresponding price decomposition index will be unity.

To illustrate that the profit decompositions are contributions to profits and not absolute ratios, Figure 2 presents the ratios of output and variable input prices and quantities relative to the benchmark vessel. Although these absolute ratios provide information on the variability of these measures across vessels and periods, they do not provide insight into what may be contributing to relative profitability. Moreover, these ratios cannot be used to construct a meaningful index of total factor productivity.

Table 6 Decomposition of profit ratios (θ), 2000

Obs	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	*K*
1	63 499	0.041	0.041	0.337	0.601	1.000	3.073	0.066
2	49 720	0.032	0.032	0.171	0.712	1.000	2.479	0.107
3	171 268	0.111	0.111	1.009	0.252	1.000	2.603	0.168
4	83 357	0.054	0.054	0.768	0.126	1.000	3.226	0.173
5	50 161	0.033	0.033	0.086	0.234	1.000	9.092	0.179
6	174 659	0.114	0.114	0.999	0.214	1.000	2.898	0.184
7	207 175	0.135	0.135	0.528	0.455	1.000	2.891	0.194
8	180 060	0.117	0.117	0.904	0.255	1.000	2.372	0.214
9	120 783	0.079	0.079	0.798	0.219	1.000	2.000	0.224
10	143 895	0.094	0.094	0.309	0.475	1.000	2.726	0.235
11	61 250	0.040	0.040	0.087	1.046	1.000	1.820	0.240
12	338 876	0.221	0.221	0.646	0.507	1.000	2.691	0.250
13	116 704	0.076	0.076	0.372	0.191	1.000	4.198	0.255
14	342 265	0.223	0.223	0.656	0.442	1.000	2.786	0.276
15	233 326	0.152	0.152	0.425	0.420	1.000	3.083	0.276
16	68 215	0.044	0.044	0.111	0.285	1.000	4.917	0.286
17	134 064	0.087	0.087	0.387	0.202	1.000	3.650	0.306
18	773 136	0.503	0.503	3.078	0.693	1.000	0.734	0.321
19	116 301	0.076	0.076	0.149	0.214	1.000	6.647	0.357
20	84 078	0.055	0.055	0.019	0.256	1.000	24.690	0.454
21	132 867	0.086	0.086	0.072	0.126	1.000	20.240	0.469
22	274 564	0.179	0.179	0.719	0.171	1.000	2.843	0.510
23	531 489	0.346	0.346	0.509	0.410	1.000	2.504	0.663
24	484 857	0.316	0.316	0.280	0.734	1.000	2.131	0.719
25	122 123	0.079	0.079	0.019	0.476	1.000	9.988	0.878
26	1 536 531	1.000	1.000	1.000	1.000	1.000	1.000	1.000
27	257 087	0.167	0.167	0.066	0.520	1.000	3.887	1.262
28	880 492	0.573	0.573	0.190	0.676	1.000	1.286	3.459

Table 7 Decomposition of profit ratios (θ), Means

Obs	*No.*	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	*K*
All years	120	232 897	0.085	0.099	0.271	0.279	1.044	3.955	0.318
Small	73	122 552	0.057	0.068	0.304	0.261	1.037	4.058	0.201
Large	47	404 282	0.156	0.182	0.226	0.309	1.056	3.800	0.648
1997	30	176 336	0.055	0.076	0.211	0.199	1.057	5.643	0.303
Small	19	90 327	0.037	0.051	0.201	0.187	1.049	6.368	0.203
Large	11	324 896	0.108	0.149	0.229	0.221	1.073	4.581	0.602
1998	33	203 622	0.074	0.090	0.283	0.238	1.068	4.117	0.306
Small	20	99 080	0.047	0.057	0.280	0.221	1.059	4.435	0.195
Large	13	364 457	0.151	0.183	0.288	0.263	1.082	3.670	0.608
1999	29	282 937	0.113	0.126	0.307	0.374	1.047	3.105	0.337
Small	17	159 367	0.083	0.092	0.417	0.359	1.034	2.913	0.204
Large	12	289 665	0.174	0.194	0.198	0.395	1.064	3.398	0.686
2000	28	276 171	0.117	0.117	0.297	0.360	1.000	3.313	0.331
Small	17	149 369	0.081	0.081	0.390	0.336	1.000	3.078	0.202
Large	11	472 139	0.205	0.205	0.195	0.399	1.000	3.713	0.709

Note: The arithmetic mean is used to average over the profit values, whereas the geometric mean is used to average over the indexes. Vessel tonnage (K) is used to split up observations into 'small' and 'large' vessels. Small vessels are defined as those being lighter than the sample average ($K < 0.318$), and large vessels are defined as those being heavier than the sample average ($K > 0.318$). 'No.' denotes the number of vessels in each year/size category.

Table 8 Decomposition of profit ratios (θ), means by fleet type

Obs	*No.*	*Profit*	θ_s	θ	*R*	*PO*	*PF*	*PL*	*K*
All years	120	232 897	0.085	0.099	0.271	0.279	1.044	3.955	0.318
Offshore	18	428 283	0.146	0.168	0.306	0.427	1.042	3.121	0.397
Inshore	67	248 675	0.095	0.111	0.204	0.300	1.053	4.350	0.394
Danish	35	102 207	0.051	0.061	0.439	0.194	1.028	3.724	0.188
1997	30	176 336	0.055	0.076	0.211	0.199	1.057	5.643	0.303
Offshore	4	209 876	0.072	0.100	0.099	0.372	1.053	6.143	0.420
Inshore	16	232 466	0.071	0.099	0.205	0.208	1.072	5.708	0.378
Danish	10	73 112	0.032	0.044	0.297	0.145	1.036	5.357	0.186
1998	33	203 622	0.074	0.090	0.283	0.237	1.068	4.117	0.306
Offshore	4	250 799	0.090	0.109	0.134	0.363	1.081	4.949	0.420
Inshore	18	263 870	0.096	0.116	0.276	0.249	1.081	4.154	0.378
Danish	11	87 880	0.045	0.055	0.387	0.187	1.043	3.793	0.192
1999	29	282 937	0.113	0.126	0.307	0.374	1.047	3.105	0.337
Offshore	5	569 411	0.242	0.270	0.750	0.485	1.044	1.862	0.381
Inshore	17	255 789	0.102	0.114	0.170	0.402	1.058	3.802	0.414
Danish	7	144 242	0.083	0.092	0.684	0.260	1.020	2.733	0.187
2000	28	276 171	0.117	0.117	0.297	0.360	1.000	3.313	0.331
Offshore	5	603 869	0.226	0.226	0.594	0.480	1.000	2.104	0.377
Inshore	16	240 233	0.115	0.115	0.176	0.395	1.000	4.026	0.410
Danish	7	124 248	0.076	0.076	0.597	0.236	1.000	2.935	0.184

Table 9 Adjustment terms

Year	Aggregate	Offshore	Inshore	Danish
1997	0.721	0.751	0.709	0.830
1998	0.826	0.825	0.827	0.900
1999	0.898	0.908	0.889	0.931
2000	1.000	1.000	1.000	1.000

Note: Using the stock indexes in Table 2, the adjustment terms for each fleet are ($stock^{2000}/stock^{b}$) for year b = 1997, . . . , 2000, as in Equation (10), where the reference year is 2000.

5. Productivity, quota trading, and the vessel buy-back

Observation of the profit decompositions reveals a number of insights about vessel performance in the fishery.

5.1 Output prices

Scatter plots of the *PO* index in Figure 1 suggest that the contribution to profits from the implicit output price for all vessel classes rises over time. Table 7 also shows that both small and large vessel classes – defined relative to average vessel size – experienced increases in the contribution to relative profits from rising output prices. For instance, Table 7 indicates that the geometric mean for *PO*, for small and large vessels, rose from 0.199 and 0.238 in 1997 and 1998 to 0.374 and 0.360 in 1999 and 2000. Table 8 provides

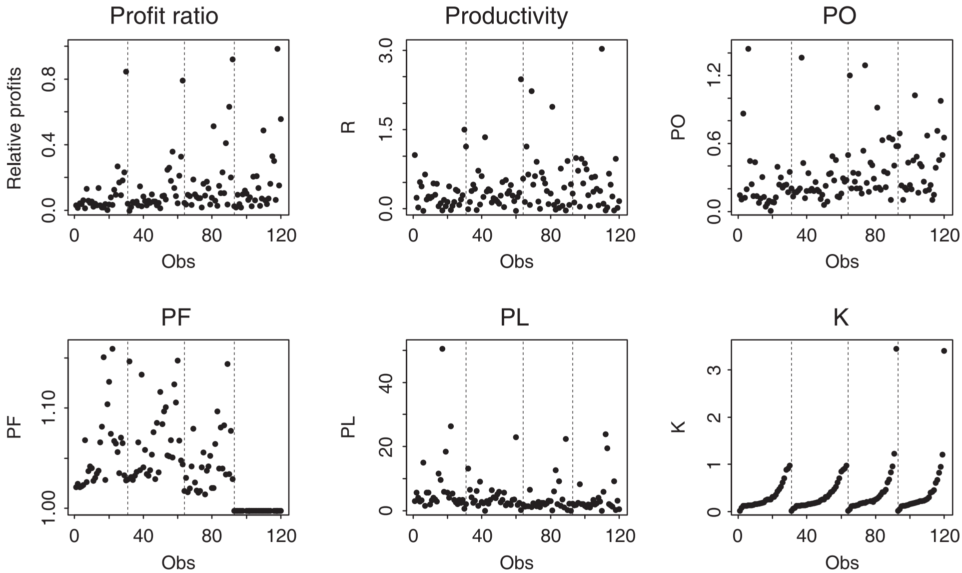

Figure 1 Profit-ratio decomposition.

a similar result when the performance of vessels is partitioned into the three trawler fleets instead of by vessel size.

5.2 Input (fuel and labour) prices

No consistent trend is apparent for the variable inputs (PF) across vessel sizes, the three trawler fleets, or over time, but the contribution of labour to profits does decline over the period. The trend in the relative contribution of labour to profits is consistent with an increase in the value of landings over the period that raised crew remuneration.

5.3 Profit performance

Our results suggest that since 1997 profit performance in the fishery has improved for small and large vessels and, on average, for vessels in each of the three trawler fleets. However, the extent to which this is attributable to the combined licence buy-back and industry-assisted brokerage services, and with it increased quota trading, is not immediately clear. The profitability of both small and large vessels in Table 7, and also the three trawler fleets given in Table 8, improved over the period 1997–2000 because of a rise in output prices, but this was independent of the buy-back because the fishery has been managed by ITQs since 1992. A possibility exists, however, that the establishment of limited brokerage services for trading quota in 1997 may have stimulated increases in output prices by allowing fishers to adjust their harvests to better suit market conditions and their catches. Such an outcome

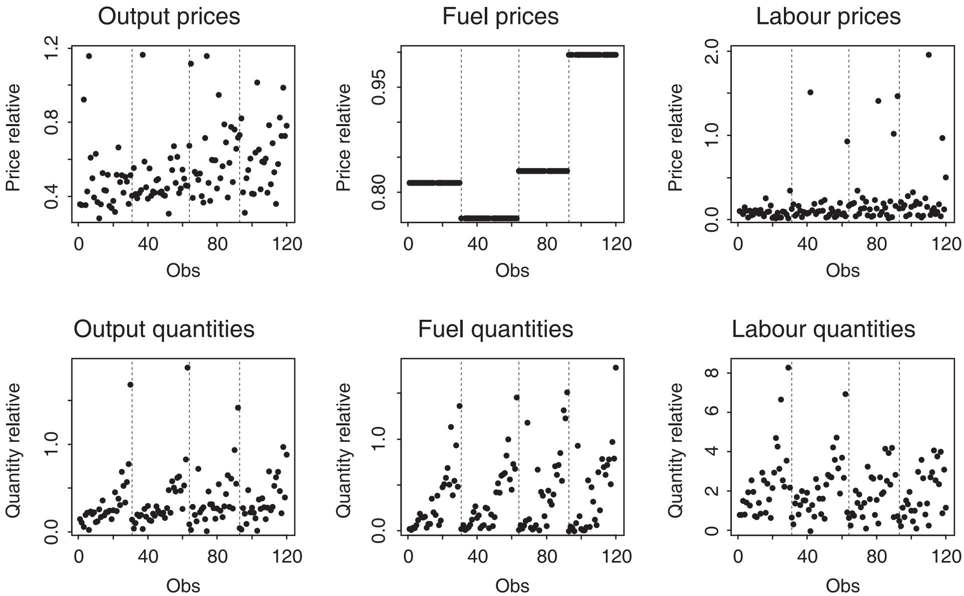

Figure 2 Price and quantity relatives.

is supported by the fact that annual lease quota trades increased by over 50 per cent for the period 1997–2000 compared with the period 1992–1996.

5.4 Productivity performance

If the vessel buy-back and increased quota trading combined did have a positive economic benefit to fishers, it should also have raised overall vessel productivity. The evidence from the profit decompositions is that the overall contribution of productivity to profits (*R*) rose over the period 1997–2000. Productivity increased the most for the offshore otter trawl fleet followed by the Danish seine fleet, but the inshore otter trawl fleet experienced a slight fall in the productivity contribution to profits from 1997 to 2000. This decline with the inshore fleet is due to poor performance of large inshore otter trawl vessels. It also explains why large vessels as a whole experienced a slight decline in productivity over the period, as shown in Table 7, despite the fact that the few large offshore otter trawl vessels experienced very large productivity gains, as indicated in Table 8. The good performance of the offshore trawl fleet also explains why the difference in the mean of the profit ratio increased between the offshore and the inshore fleets, and also with the Danish seine fleets, between 1997 and 1998, and 1999 and 2000.

A comparison of productivity between small and large vessels shows that both vessel classes experienced a productivity jump in 1998 with the productivity contribution to profits rising by 39 per cent for small and 26 per cent for large vessels. Large productivity gains were also experienced by the three trawler fleets and arose, at least in part, because the total allowable catch for all the quota species was nonbinding prior to 1997. Thus, despite the existence of individual harvesting rights – and partly due to the fact that TAC is not binding for many species – the removal of capacity with the licence buy-back helped to increase the landings of the fishers who remained. This is because the 27 licence holders that were removed by the licence buy-back from the SETF were obliged to sell their quota holdings, thereby allowing remaining fishers to optimise their scale of production and raise productivity. To the extent that the offshore larger boats may have been more constrained in terms of the mix of quota holdings, such a change may have benefited them to a greater extent than other vessels. Further support for the buy-back and increased quota trading as the causes for the productivity increases is that such gains were simultaneous with a decline in catch per unit of effort for seven of the 16 quota species over the period 1997–1998 (AMS Search Ltd. 2000), and a decline in the overall stock and also stock indexes for the three trawler fleets.

5.5 Licence buy-back and quota trading

The empirical evidence provides support for the hypothesis that the combined licence buy-back and the establishment of a brokerage service instituted in the fishery in 1997 have had a positive impact on profitability via productivity improvements. Unlike vessel or licence buy-backs implemented in other fisheries, such as British Columbia's salmon fishery or the US north-east multispecies fisheries (Holland *et al*. 1999), it has occurred within a fishery managed by individual and transferable output controls. Thus, the SETF offers a unique 'natural experiment' where a buy-back, coupled with ITQs, appears to provide ongoing benefits to fishers.

Possible explanations for why the buy-back and the quota trading system together were effective at improving economic performance arise from the nature of sunk costs in fisheries and transactions cost in exchanging quota. The larger the sunk costs, all else equal, the longer is the interval that a fisher will remain in an industry without reinvestment (Vestergaard *et al*. 2005). Given that there are very few, if any, profitable alternatives for vessels outside of the SETF, this is likely to have slowed the transition to optimal fleet structure. Thus, additional financing in the form of the 1997 buy-back of licences encouraged the exit of vessels that otherwise would have been delayed. At the same time, the quota brokerage service reduced transactions costs for trading quota and, thus, allowed trades that previously did not take place (Stavins 1995). This also had a positive effect on profits as it allowed fishers to better optimise their harvesting decisions over the sample period.

Because the payoffs of the combined buy-back and brokerage service are ongoing, occurring in every year of the sample period, it thus appears that the SETF – managed by individual harvesting rights and with an effective quota trading system since 1997 – has been able to partially avoid rent dissipation or the incentive for increases in fishing effort that often follows buy-backs

(Campbell 1989; Weninger and McConnell 2000). Nevertheless, given that TAC is not binding for most species in the SETF, at least until recently, it is possible that the productivity gains achieved over the sample period in this study may have been dissipated in subsequent years.

6. Concluding remarks

The paper presents the first *ex post* analysis of individual firm profits and productivity in a fishery following a vessel/licence buy-back coupled with increased quota trading. In particular, the paper analyses a 'natural experiment' of the effects of a 1997 scheme to reduce fishing capacity and the transactions costs associated with quota trading in the South-east Trawl Fishery of Australia. Using an innovative index method that decomposes the contributions of output prices, input prices, vessel size, and productivity to relative profits, the economic performance of vessels is analysed in the year of the buy-back, and for 3 years afterwards.

The results indicate a large range in the relative profits and productivities of vessels within the fishery and measurable differences across vessel sizes and trawler fleets. In the 3 years following the buy-back and the establishment of an industry-assisted quota brokerage service, all vessels have benefited from a rise in output prices. The results also indicate a substantial increase in mean stock-adjusted productivity for all vessel size classes and trawler fleets the year immediately following the licence buy-back and the establishment of the quota brokerage service.

The findings suggest that the buy-back, coupled with individual tradeable harvesting rights and greater quota trading through the establishment of a quota brokerage service, have been successful at improving economic performance. Such a desirable outcome is in direct contrast to the unfavourable long-term outcomes often associated with vessel and licence buy-back in fisheries managed exclusively by input controls.

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