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Productivity change and fleet restructuring after transition to individual transferable quota management

Rolf Färe [a], Shawna Grosskopf [b], John Walden [c,*,1]

[a] Department of Economics and Applied Economics, Oregon State University, Ballard Ext Hall, Oregon State University, Corvallis, OR 97331, USA
[b] Department of Economics, Ballard Ext Hall, Oregon State University, Corvallis, OR 97331, USA
[c] NOAA/NMFS, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543, USA

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ABSTRACT

Productivity change after transition to an individual transferable quota (ITQ) management system is driven by exit of some vessels, entry of other vessels, and changes in productivity of existing vessels. Generally, it is thought that an ITQ system boosts productivity due to the exit of less productive vessels. However, ITQ management systems also create an additional barrier to entry, and more productive vessels may not be able to enter the fishery. This study constructs the Färe–Primont index to measure productivity change for the Mid-Atlantic surf clam and ocean quahog fishery over a 32 year time period, which includes both pre and post-ITQ time periods. The index is then combined with a biomass change index to arrive at a measure of biomass adjusted productivity change. Results show that when biomass changes are considered, positive productivity gains occurred throughout the time period. Further examination of contributions from entering and survivor vessels show that entering vessels had little impact on aggregate productivity, but on an individual basis, they eventually were equal in productivity to survivor vessels.

1. Introduction

Productivity and productivity change are important drivers of firm profitability, and their importance to changing standards of living is one reason why they have been extensively studied [1]. Firms generally can increase profitability through increased productivity, higher output prices, lower input prices, or some combination of all three [2]. Unfortunately, fishing vessels harvesting a publicly controlled resource are limited in their ability to influence prices, meaning increased productivity may be their only available means of increasing profits through time.

The study of productivity, and productivity change in fisheries has always drawn interest from individual researchers but until recently has not been systematically estimated. Within the past year both Australia [3] and the United States [4] have released reports, which tracked productivity change in key fisheries. Past studies have focused on productivity changes after policy changes implementing Individual Transferable Quota (ITQ) management. These studies were important because pre-ITQ, expectations are that productivity will improve as quotas are traded from less efficient vessels to more efficient vessels [5]. Measuring productivity change post-ITQ provides information as to whether positive productivity changes have in fact occurred.

A review of studies focusing on fisheries where ITQs have been implemented showed somewhat mixed results concerning whether positive productivity change occurred. For example, in the British Columbia halibut fishery, the greatest benefit associated with a shift to individual harvesting rights was an increase in output prices, rather than productivity gains [6]. In the Nova Scotian mobile gear fishery, it was demonstrated that ITQ programs encourage better quality catches leading to higher prices, hence short-run gains in this fishery were largely due to output price increases [7]. In the southeast Australian trawl fishery, both positive changes in output prices and vessel productivity occurred after implementation of a vessel buyback, which was coupled with a brokerage service that allowed quota trading [8]. After adoption of ITQs in the Australian Rock Lobster fishery, average landings per vessel, landings per labor input, and technical change all increased [9]. In the U.S. mid-Atlantic surfclam and ocean quahog ITQ fishery, it was found that technical efficiency increased pre-ITQ as owners behaved strategically in order to gain quota share [10]. A recent study of this same fishery showed positive productivity change immediately after implementation of ITQs, followed by declining productivity [11].

* Corresponding author.
E-mail addresses: Rolf.Fare@Oregonstate.edu (R. Färe), Shawna.Grosskopf@oregonstate.edu (S. Grosskopf), John.Walden@Noaa.Gov (J. Walden).
[1] Senior authorship shared.

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This study seeks to extend a prior study of the mid-Atlantic surfclam and ocean quahog ITQ fishery [11] by estimating productivity before and after conversion to an (ITQ) management system using the Färe–Primont index [12]. The Färe–Primont index has attractive theoretical properties [12] and practical advantages to answer questions at both an individual vessel and fleet level. It does not require balanced panel data as do the Malmquist or Hicks-Moorsteen index. Productivity change between years is calculated based on aggregate industry productivity change. By applying the Färe–Primont index, this study seeks to determine (1) whether fleet productivity increased; (2) if productivity change is being driven by productivity increases of survivor vessels, or greater productivity of entering vessels, and (3) whether exiting vessels are less productive than survivor or entering vessels.

This article proceeds as follows: First, the Mid-Atlantic surfclam and ocean quahog fishery is described. The Färe–Primont index is then introduced, along with an explanation of how it is modified from the original approach proposed by [12]. The index is then used to measure productivity change for the Mid-Atlantic surfclam and ocean quahog fleet. It is then adjusted by a measure of biomass change to arrive at a measure of biomass adjusted productivity. Results are shown separately for exiting, continuing and entering vessels to see how fleet dynamics influenced the overall index, and whether there were substantial differences between each group of vessels.

1.1. The surfclam and ocean quahog ITQ fishery

Surfclams and ocean quahogs have been managed by the The Mid-Atlantic Fishery Management Council through an annual quota setting process since 1977. Both species are bivalve mollusks, distributed along the mid-Atlantic coast of the United States, and are commercially harvested by vessels using hydraulic dredges. Generally, surfclams are located at shallower depths than ocean quahogs. Processors purchase the harvested clams from vessels, and transform them into breaded clam strips, soups and chowders.

The majority of both the surfclam and ocean quahog resource is within the United States Exclusive Economic Zone (EEZ, 3-200 miles from shore), and resides at depths between 20 and 80 m. There are minor state water surfclam fisheries, contributing about 10% of the total surfclam landings, and a small fishable resource of ocean quahogs found in Maine state coastal waters, which contributes about three percent of total landings. The Maine quahog fishery produces a product which goes to a fresh market instead of being sold to processors. Almost half of the current surfclam stock is found in the Georges Bank (GBK) resource area, which except for recent experimental fishing, has not been harvested since 1989 due to paralytic shellfish poisoning (PSP) toxins found in surfclam meats.

From 1979 through 1989, regulators sought to keep within their prescribed catch limits for surfclams and ocean quahogs in the EEZ through a system, which restricted fishing time for each vessel on a quarterly basis. However, the number of active vessels in the fishery increased during this time period, along with average landings (Fig. 1). The response by regulators was to decrease allowable fishing time per vessel (Fig. 2), in order for the harvest to stay within prescribed catch limits. During the pre-ITQ time period, entry was likely a strategic decision as owners foresaw the ITQ system, which the Council was moving to adopt, and sought to build catch histories in order to receive a larger share of the potential ITQ [10]. Under the ITQ system, once the total quota of each species was determined, quota shares were to be allocated both at no cost, and based on catch histories. An owner's percentage share of the quota will not change unless they sell their share to another entity, but their individual quota within a year can change as the

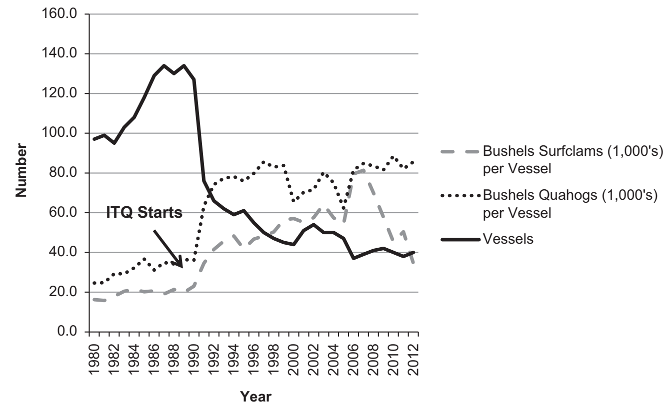

Fig. 1. Number of vessels, bushels of surfclams and ocean quahogs harvested per vessel 1980–2012.

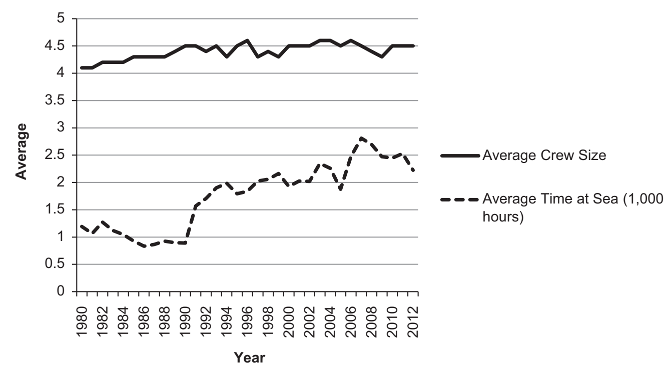

Fig. 2. Average time at sea and crew size per vessel 1980–2012.

overall quota is adjusted up or down based on underlying biomass conditions. Owners cannot carry forward any unused quota to the next year.

In 1990, the surfclam quota was set at 2,850,000 bushels where it remained until 1995 when it was lowered to 2,565,000 bushels. In 2001, the quota was raised to 2,850,000 bushels and then subsequently increased to 3,400,000 bushels in 2004, where it has remained since. Quota overages occurred in 1990, but since 2004 the quota was never fully harvested. The ocean quahog quota was 5,300,000 bushels in 1990 and declined gradually in the mid-1990s, before being lowered to 4,500,000 bushels in 1999. The ocean quahog quota was raised to 5,333,000 bushels in 2005 where it has remained. Since 1980, the ocean quahog quota has never been exceeded [13]. Between 2005 and 2012, landings averaged 62% of the quota.[2]

Once the ITQ system started in 1990, a large reduction in the number of active vessels took place. Exit then continued at a much reduced rate over the next 20 years (Fig. 1). Because there were fewer vessels, catch per vessel of both surfclams and ocean quahogs increased steadily post-ITQ (Fig. 1). In 2007, surfclam landings peaked at more than 80,000 bushels per vessel, before declining in subsequent years. Similarly, ocean quahog landings were more than 80,000 bushels per vessel in 2007, and then leveled off in subsequent years.

Along with increasing outputs per vessel, input usage also changed. Both the capital employed and the time it was deployed at sea post-ITQ increased (Figs. 2 and 3). Vessel size based on gross tonnage and length increased 18% and 6%, respectively, between 1989 and 2012, while average horsepower increased 34%. Horsepower gains were even greater compared to 1980, the first year in

[2] This does not include the Maine mahogany quahog fishery.

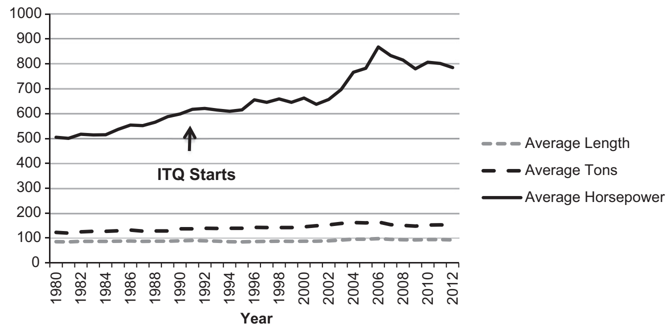

Fig. 3. Vessel physical characteristics 1980–2011.

the time series, increasing 56%. Vessel time at sea increased 248% between 1989 and 2012, while crew size stayed relatively flat. This was expected as the management system shifted from one where time at sea was restricted (input controls), to one where overall catch was limited (output controls).

Overall, post-ITQ there was both an increase in capital used, as larger vessels replaced smaller vessels, and an increase in landings per vessel as production was shifted off some vessels and onto others. Under a fixed quota, vessels can become more profitable by increasing their productivity, changing their output mix, buying additional quota, or some combination of the three. Capital is not always easy to shed, meaning vessel exit is likely to occur over many years. Once a fleet reaches its long-run equilibrium structure, the remaining vessels should be the most efficient [10].

2. Methods

Many productivity indexes are measures of changes in levels of productivity, and thus this section starts by demonstrating a method for measuring levels of productivity. Beginning with the single output case in which one output is produced with a single input to illustrate the methodology, the approach then turns to the general case in which there are many outputs, $y \in \Re^M_+$, produced from a vector of inputs, $x \in R^N_+$. Therefore, assume first that $M=N=1$ and the level of productivity is simply the ratio of output to input:

$$PROD = y/x. \tag{1}$$

In order to generalize this index to multiple outputs and inputs, define a quantity index for outputs and a quantity index for inputs, which are of the form developed by Malmquist, and are based on distance functions. Let technology be defined as $T=\{(x,y):x$ can produce $y\}$, then the input and output distance functions are defined as

$$D_i(y, x) = sup\{\lambda: \ : (x/\lambda, y) \ \in T\} \tag{2}$$

and

$$D_o(x, y) = inf\{\theta: \ : (x, y/\theta) \ \in T\}, \tag{3}$$

respectively [14,15]. These functions are homogeneous in the scaled variables, i.e., inputs and outputs, respectively. Using these definitions and the homogeneity property, the definition of productivity may now be rewritten as

$$PROD = \ y/x = \frac{y/1}{x/1} = \frac{D_o(1, y)/D_o(1, 1)}{D_i(1, x)/D_i(1, 1)} \tag{4}$$

Thus PROD is the ratio of an output quantity index:

$$Q_o(y) = D_o(1, y)/D_o(1, 1) \tag{5}$$

and an input quantity index:

$$Q_i(x) = D_i(1, x)/D_i(1, 1), \tag{6}$$

i.e.,

$$PROD = Q_o(y)/Q_i(x). \tag{7}$$

Note that both $x=1$, and $y=1$ have been used as the reference input and output vectors. Other possibilities exist, of course [2]. However, there is no theoretical “best” reference point. Distance functions may then be defined for $x \in \Re^N_+$ and $y \in \Re^M_+$, and these vectors may be inserted into the quantity indexes and therefore into PROD, giving the desired multifactor level measure of productivity in terms of output and input quantity indexes.

Before discussing aggregation, it is demonstrated how these indexes may be estimated using activity analysis or Data Envelopment Analysis (DEA) techniques. Assume that at each time period there are $k=1,\ldots,K$ observations of inputs $x \in \Re^N_+$ and $y \in \Re^M_+$outputs. From these (x^k, y^k), $k=1,\ldots,K$ data points the distance functions defined above are estimated. For each observation k' the output distance function is the solution to the following linear programming problem:

$$\left(D_o\left(1, y^{k'}\right)\right)^{-1} \ = \ \max \theta \tag{8}$$

$$s.\ t. \ \sum_{k=1}^{K} z_k y_{km} \geqq \theta y_{k'm}\ , \quad m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leqq 1, \qquad n = 1, \ldots, N$$

$$z_k \geqq 0, \qquad k = 1, \ldots, K$$

where the z_k, $k=1,\ldots,K$ are the intensity variables. The second component in the output quantity index is common to all $k=1,\ldots,K$ observations and is estimated as the solution to

$$(D_o(1, \ 1))^{-1} = \ \max \theta \tag{9}$$

$$s.\ t. \ \sum_{k=1}^{K} z_k y_{km} \geqq \theta \cdot 1, \quad m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leqq 1, \qquad n = 1, \ldots, N$$

$$z_k \geqq 0, \qquad k = 1, \ldots, K$$

These are the building blocks for estimating and constructing the output quantity index $Q_o(y^k)$ for each observation. The input quantity index is estimated in a similar way, but based on input rather than output distance functions:

$$(D_i\left(1, \ x^{k'}\right))^{-1} = \ \min \lambda \tag{10}$$

s.t

$$s.\ t \ \sum_{k=1}^{K} z_k y_{km} \geqq 1, \qquad m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leqq \lambda x_{k'n}, \qquad n = 1, \ldots, N$$

$$z_k \geqq 0, \qquad k = 1, \ldots, K$$

and

$$(D_i(1,1))^{-1} = \min \lambda \tag{11}$$

$$s.t \sum_{k=1}^{K} z_k y_{km} \geqq 1, \qquad m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z_k x_{kn} \leqq \lambda \cdot 1, \qquad n = 1, \ldots, N$$

$$z_k \geqq 0, \qquad k = 1, \ldots, K$$

Outputs in the above DEA models are bushels of surfclams and ocean quahogs harvested by each vessel. Inputs are capital and labor services. Capital services are measured by the product of vessel horsepower times days fished. Vessel horsepower multiplied by days fished yields a measure of fishing power, which is often used in biological studies. Crew services are measured by crew size on each vessel times days fished. Bushels landed and days fished are obtained from federal logbook data which vessel owners are required to submit after each fishing trip. Horsepower and crew size information is collected through the federal fishing permit system which is updated yearly.

The next step is to go from individual vessel indexes of productivity based on these distance functions to an aggregate index for the fleet, which also accommodates the fact that vessels are entering, continuing, and exiting the fleet over time. Begin by defining a productivity index for all k vessels as

$$PROD = \frac{Q_o(y^1) + Q_o(y^2) + Q_o(y^3) + \ldots . Q_o(y^k)}{Q_i(x^1) + Q_i(x^2) + Q_i(x^3) + \ldots . Q_i(x^k)} \tag{12}$$

One may also define the aggregate index in terms of shares: [3] [16]

$$S_k = \frac{Q_i(x^k)}{Q_i(x^1) + Q_i(x^2) + Q_i(x^3) + \ldots . Q_i(x^k)}, \quad k = 1, 2, \ldots, k \tag{13}$$

which are used to define a share weighted aggregate index of productivity:

$$PROD = \sum_{k=1}^{K} S_K \frac{Q_o(y^k)}{Q_i(x^k)} \tag{14}$$

Alternatively, this may be written as

$$PROD = \sum_{k=1}^{K} S_K PROD^k, \tag{15}$$

where

$$PROD^K = Q_o(y^k)/Q_i(x^k).$$

It is clear that S_k is a share since $S_k >= 0$ and $\sum_{k=1}^{K} S_k = 1$, and our share weighted aggregate needs no additional assumptions to be appropriate. Note that each entering, exiting, and continuing vessel types all have the same reference technology which is derived from all observations $k=1,\ldots,K$, in each period, and that productivity for continuing, entering, and exiting vessels can be summed separately, and then aggregated into an overall productivity measure, $PROD = PROD_C + PROD_x + PROD_E$. By doing so, it is possible to measure how each group of vessels contributes to the overall productivity measure. These indexes are computed for each time period $t=1. \ldots .T$, and then a productivity change index is calculated as $Prod^t/Prod0$, where the base year (0) is 1989, the year before the ITQ program was implemented. The productivity change index is then multiplied by a biomass change index, which is discussed next, to arrive at a biomass adjusted measure of productivity change.

2.1. Biomass adjusted productivity

Because fishing vessels harvest a natural resource stock, which can grow or shrink through time, productivity change between time periods is influenced by biomasss change. If the influence of changing biomass on productivity change cannot be separated from the productivity change metric, the productivity metric will be "biased" [17–19]. Instead of using the term "biased", the terms "biomass unadjusted" (BU) or "biomass adjusted" (BA) productivity are used. The relationship between BU and BA productivity in any time period t is thought to be $TFP_{BU}=TFP_{BA}*B$, where B is a measure of biomass [20]. Here, biomass is acting as a "shifter" of biomass adjusted productivity. Since biomass adjusted productivity is the measure of interest, it is necessary to solve for TFP_{BA} yielding the following:

$$TFP_{BU} * B^{-1} = TFP_{BA} \tag{16}$$

Since the interest lies in measuring productivity change between any two periods, say $t-1$ and t, TFP^t/TFP^{t-1} is constructed as the ratio of productivity measures in periods $t-1$ and t:

$$\frac{TFP_{BA}^{t}}{TFP_{BA}^{t-1}} = \frac{TFP_{BU}^{t} * (B^t)^{-1}}{TFP_{BU}^{t-1} * (B^{t-1})^{-1}} \tag{17}$$

This simplifies to

$$\frac{TFP_{BA}^{t}}{TFP_{BA}^{t-1}} = \frac{TFP_{BU}^{t}}{TFP_{BU}^{t-1}} * \frac{B^{t-1}}{B^{t}} \tag{18}$$

All three terms in the above equations can be measured with index numbers, yielding the following:

$$ITFP_{BA} = ITFP_{BU} * IB \tag{19}$$

This means that a biomass adjusted (BA) index of TFP change is the product of the biomass unadjusted (BU) TFP index times a biomass change (IB) index. The interaction between the two indices produces a biomass adjusted index which is consistent with expectations concerning the direction of biomass adjusted productivity change. If biomass increases (decreases) in year t, relative to year $t-1$, the biomass index (IB) will be less (greater) than one, and biomass adjusted productivity will be lower (greater) than biomass unadjusted productivity.

Unless vessels in a fishery harvest a single species, biomass levels for all species harvested by the vessels, need to be included in the biomass index. A simple geometic mean index is constructed to aggregate species into a single index as follows: $\left[\prod_{i=1}^{n} \frac{B_i^0}{B_i^t}\right]^{\left(\frac{1}{n}\right)}$. B_i is a biomass measure for species i, and the t superscript denotes the time period. Again, this is somewhat different than a usual basket type quantity index [21] as the base period is in the numerator, rather than the denominator. This preserves the structure which was developed earlier in Eq. (18).

Biomass data are estimated through yearly stock assessment models, are measured in meat weight (1000 metric tons), and represent exploitable biomass (Fig. 4). Exploitable biomass is the portion of the stock, which is available for harvest. Both surfclam and ocean quahogs have portions of their biomass in the Georges bank fishing area, which just recently reopened to fishing after having been closed since 1990. The stock that is in the closed area is not included in the exploitable biomass estimate. Data from 1980 through 2012 were obtained from stock assessment documents prepared by the Northeast Fisheries Science Center [22,23]. Estimates for 2012 are projections furnished separately by the

[3] This follows the 'denominator rule'.

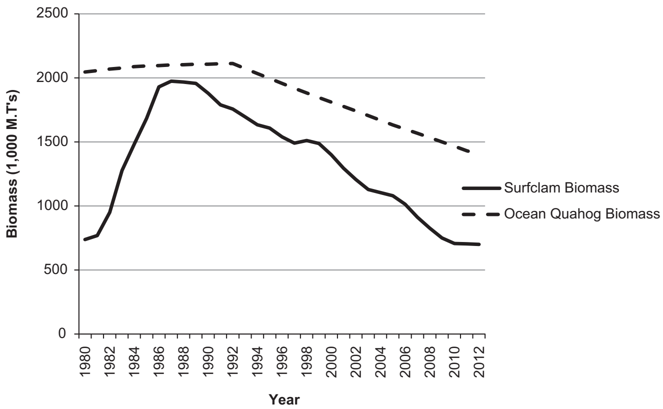

Fig. 4. Exploitable biomass (1000 Metric Tons) surfclam and ocean quahogs 1980–2012.

Northeast Fisheries Science Center based on prior year biomass estimates, landings and measures of natural mortality.

3. Results

During the 1980–2012 time period, the unadjusted productivity index ranged from a low of 0.54 in 1983, to a high of 1.09 in 1985 (Table 1). The biomass adjusted productivity index had a low value of 0.67 in 1983, and a high of 1.42 in 2010. Both the unadjusted and biomass adjusted productivity indices show an increasing trend until 1992, and then a declining trend until 2011. In the pre-ITQ time period (1980–89), there was an initial decline in the biomass unadjusted productivity index until 1983, and then an increase in both productivity and vessels, with the maximum number of vessels fishing (134) in 1987 corresponding with the highest unadjusted productivity level (1.79). Once ITQs were implemented in 1990, a large number of vessels exited in 1991 (Fig. 1). These findings, along with a decline in biomass unadjusted productivity post-ITQ are consistent with prior studies [10,11]. The trends are also consistent with published documents from the Mid-Atlantic Fishery Management Council (MAFMC), which noted in its latest specifications document that trips harvesting surfclams have increased in length, and that ocean quahog production has continued to shift to larger vessels fishing further offshore [13]. In other words, vessels are using more inputs to produce the same level of outputs.

Because results showed large fluctuations in productivity levels, and productivity change throughout the study period, mean results were generated for time periods before and after ITQ implementation (Table 2). The first period, 1980–1989 is prior to ITQ implementation, and corresponds to a period of strategic behavior by vessel owners trying to build history for the ITQ program [10]. The 21 year period after ITQ implementation was split into two periods corresponding to the 1990s and 2000s.

For the entire study period, the biomass adjusted productivity index averaged 1.09, and biomass adjusted productivity change averaged 1.19% per year. The biomass index averaged 1.36, which indicates declining biomass over time. Examination of the three time periods shows that the years 2001–2012 had the highest overall mean biomass adjusted productivity index (1.21), while the pre-ITQ (1980–1989) time period had the highest mean level of

Table 1
Biomass adjusted and unadjusted productivity and productivity change 1980–2012.

	Year	Vessels	Productivity level	Productivity index	Biomass index	Biomass adjusted productivity index	Biomass adjusted productivity change
	1980	97	1.29	0.74	1.65	1.22	
	1981	99	1.23	0.71	1.61	1.14	−6.6%
	1982	95	1.2	0.69	1.45	1.00	−12.5%
	1983	103	0.94	0.54	1.25	0.67	−32.6%
	1984	108	1.65	0.95	1.15	1.09	62.4%
	1985	118	1.9	1.09	1.08	1.18	7.9%
	1986	129	1.71	0.98	1.01	0.99	−16.0%
	1987	134	1.79	1.03	1.00	1.03	3.4%
	1988	130	1.31	0.75	1.00	0.75	−26.7%
	1989	134	1.74	1.0	1.00	1.00	33.1%
Introduction of ITQs	1990	125	1.5	0.86	1.02	0.88	−12.1%
	1991	75	1.44	0.83	1.04	0.86	−1.7%
	1992	66	1.57	0.90	1.05	0.95	10.0%
	1993	62	1.62	0.93	1.08	1.01	6.0.0%
	1994	59	1.57	0.90	1.11	1.01	−0.3%
	1995	61	1.6	0.92	1.13	1.04	3.6%
	1996	55	1.62	0.93	1.17	1.09	4.5%
	1997	50	1.6	0.92	1.20	1.10	1.4%
	1998	47	1.46	0.84	1.20	1.01	−8.5%
	1999	45	1.55	0.89	1.22	1.09	8.0%
	2000	44	1.39	0.80	1.28	1.02	−6.6%
	2001	51	1.4	0.80	1.34	1.08	5.7%
	2002	54	1.6	0.92	1.40	1.29	19.5%
	2003	50	1.46	0.84	1.46	1.23	−4.6%
	2004	50	1.36	0.78	1.50	1.17	−4.8%
	2005	47	1.27	0.73	1.53	1.12	−4.5%
	2006	37	1.42	0.82	1.59	1.30	16.5%
	2007	39	1.27	0.73	1.70	1.24	−4.8%
	2008	41	1.19	0.68	1.80	1.23	−0.5%
	2009	41	1.19	0.68	1.91	1.31	6.2%
	2010	40	1.24	0.71	2.0	1.42	8.6%
	2011	38	1	0.57	2.02	1.16	−18.2%
	2012	38	1.01	0.58	2.05	1.19	2.2

Table 2
Average productivity and productivity change by decade, 1980–2012.

Time period	Management	Unadjusted productivity index	Average productivity change (unadjusted) (%)	Average biomass index	Average biomass adjusted productivity index	Average biomass adjusted productivity change (%)
1980–1989	Pre-ITQ	0.85	6.96	1.22	1.01	1.36
1990–1999	ITQ	0.89	−0.93	1.12	1.00	1.10
2000–2012	ITQ	0.74	−2.83	1.66	1.21	1.14
1980–2012		0.82	0.52	1.36	1.09	1.19

yearly biomass adjusted productivity change (1.36%).

Contrasting the unadjusted productivity levels with the biomass adjusted results, the unadjusted productivity index averaged 0.82 for the entire time period, and was below one for each of the individual time periods. Average productivity change was 6.96% in the pre-ITQ (1980–1989) time period, and then was negative for the remaining two time periods. This trend is consistent with the results found using the Malmquist index where positive productivity gains before ITQ implementation were followed by negative gains post-ITQ [11]. In the Malmquist index work, optimization routines may or may not be fully capturing the influence of biomass. Since there is only one biomass estimate per year which all vessels face, it may be having little or no influence on the position of the production frontier. There is no doubt that the exploitable biomass has declined over time, meaning that in order to produce the same output, vessels will have to use their inputs more productively. Here, the biomass adjusted productivity metric can be thought of as being productivity change normalized by biomass change.

3.1. Fleet dynamics

Once the ITQ system was implemented, expectations were that productivity would increase through both replacement of capital, and shifting of harvest from less productive to more productive vessels. It was expected that more productive vessels would enter, less productive vessels exit, and vessels that continued fishing would increase their productivity through purchase of quotas from less productive vessels. This process was expected to continue for several years until the fleet reached an equilibrium based on available quota and vessel characteristics [10].

The impact of entry and exit on fleet productivity was examined by placing vessels in one of three groups in each year. The first group consisted of vessels that exited after the current year (exit).The second were vessels that continued in the next year (continue), and the third were those that entered in the current year (enter). For example, of the vessels fishing in 1981, eight vessels did not fish in 1982, 91 vessels did fish in 1982, and eight vessels fished in 1981 that did not do so in 1980 (Table 3). It should be noted that vessels can (and do) enter and exit in the same year, and that vessels entering one year, may then exit in subsequent years. As vessels exit, fleet productivity can be improved as harvest shifts from exiting vessels, which are presumably lower productivity, to more productive vessels.

The years prior to implementation showed a build-up in vessels over time as vessel owners sought to build-up catch histories in order to capture more of the quota (which was being freely distributed). During the first year of ITQ implementation (1990), there was a large exit of vessels (50), after which time the number of vessels slowly declined with very little entry. The fleet productivity level in a given year will equal the sum of the indices for continuing and exiting vessels (Table 4). Vessels that enter in a given year will also be part of the continuing and exiting group, since those vessels either continue to the next year, or cease fishing and exit. Because the majority of vessels within a given year were continuing vessels, the magnitude and change in the

Table 3
Fleet size, and the number of entering, exiting, and continuing vessels 1980–2012

Year	Exit	Continue	Enter	Total
1980	6	91		97
1981	8	91	8	99
1982	3	92	4	95
1983	5	98	11	103
1984	5	103	10	108
1985	4	114	15	118
1986	7	122	15	129
1987	6	128	12	134
1988	2	128	2	130
1989	15	119	6	134
1990	50	75	5	125
1991	11	64	0	75
1992	8	58	2	66
1993	8	54	4	62
1994	3	56	5	59
1995	8	53	5	61
1996	7	48	2	55
1997	5	45	2	50
1998	6	41	2	47
1999	3	42	4	45
2000	1	43	2	44
2001	3	48	8	51
2002	7	47	6	54
2003	4	46	3	50
2004	5	45	4	50
2005	10	37	2	47
2006	2	35	0	37
2007	1	38	4	39
2008	5	36	3	41
2009	3	38	5	41
2010	4	36	2	40
2011	2	36	2	38
2012	2	36	4	38

productivity index is generated by vessels within the continuing group. In terms of entering vessels, the highest contribution occurred in 1985 (0.27), which was one of two years that entry was at a maximum (15 vessels). The productivity level for continuing vessels peaked in 1985 (1.85), which was before ITQs were implemented, and corresponds to a time period when vessels were building catch history in anticipation of the ITQ program.

Because the contribution of each vessel group to the aggregate productivity level is being influenced by vessel numbers, average productivity per vessel for exiting, continuing and entering vessels was estimated for five year periods from 1980 to 2012 (Table 5). Since in some years there was no entry, or little exit, constructing averages over a five year time period gave more insight than yearly averages.

During the 1980s, vessels that exited had lower average productivity than either the continuing group, or the entering group (Table 5). Entering vessels in the period 1985–1989, had slightly lower productivity than continuing vessels (1.07 vs. 1.15). After the transition to ITQs in the 1990s, results were mixed. For example, between 1990 and 1994, entering vessels had the highest average productivity, while they had the lowest average productivity between 1995 and 1999. The decline in average productivity for entering vessels between 1995 and 1999 was unexpected. Generally, exiting vessels had the lowest average productivity, with

Table 4
Unadjusted productivity levels for entering, exiting and continuing vessels.

Year	Exit	Productivity continue	Enter	Total
1980	0.01	1.28		1.29
1981	0.02	1.21	0.03	1.23
1982	0.01	1.19	0.01	1.2
1983	0.03	0.91	0.04	0.94
1984	0.01	1.64	0.08	1.65
1985	0.05	1.85	0.27	1.9
1986	0.02	1.69	0.14	1.71
1987	0.01	1.78	0.1	1.79
1988	0.0005	1.31	0.0033	1.31
1989	0.07	1.67	0.02	1.74
1990	0.08	1.42	0.17	1.5
1991	0.02	1.42	0	1.44
1992	0.1	1.53	0.04	1.57
1993	0.08	1.54	0.04	1.62
1994	0.001	1.57	0.04	1.57
1995	0.02	1.58	0.01	1.6
1996	0.03	1.59	0.0006	1.62
1997	0.03	1.57	0.0022	1.6
1998	0.19	1.27	0.0015	1.46
1999	0.003	1.55	0.01	1.55
2000	0.02	1.37	0.02	1.39
2001	0.002	1.4	0.03	1.4
2002	0.09	1.51	0.24	1.6
2003	0.03	1.43	0.03	1.46
2004	0.09	1.27	0.02	1.36
2005	0.15	1.12	0.01	1.27
2006	0.02	1.4	0	1.42
2007	0.02	1.25	0.05	1.27
2008	0.04	1.15	0.01	1.19
2009	0.002	1.19	0.04	1.19
2010	0.02	1.22	0.01	1.24
2011	0.01	0.99	0.005	1
2012		1	0.01	1.01

Table 5
Average unadjusted productivity for entering, exiting and continuing vessels 1980–2012.

Time period	Exit Geometric mean	Continue Geometric mean	Enter Geometric mean
1980–1984	0.74	0.86	
1985–1989	0.80	1.15	1.07
1990–1994	0.60	1.37	1.54
1995–1999	1.00	1.48	0.32
2000–2004	1.43	1.38	1.49
2005–2009	0.92	1.19	1.09
2010–2012			0.71

the exception of 1995–1999, and 2000–2004. In both time periods, exiting vessels had higher productivity than one of the other two groups. From 2000 to 2009, there was little difference in average productivity among the three groups. Average differences were generally less than 0.2. This indicates that other factors may have been responsible for entry and exit, rather than productivity differences. After the initial 10 year period of ITQs, it is likely that the surviving fleet was made up of the most productive vessels (in terms of pre-ITQ vessels). The shift of catch from less productive to more productive vessels is a topic for further research. However, a basic methodology for answering this question has been outlined [24], which would need to be adjusted to incorporate our index number approach.

4. Discussion

It is expected that an ITQ system will increase overall productivity within a fishery, as more productive vessels replace less productive vessels. Particularly after the year 1995, biomass adjusted productivity gains increased in this fishery. Consistent with expectations, exiting vessels generally had lower average productivity than either entering or continuing vessels based on five year intervals within the study period. Entering vessels were not necessarily more productive on average, than continuing vessels during these five year intervals. This was somewhat surprising, since entering vessels need to purchase, or lease quota from existing quota holders to fish. Because entering vessels need to pay for quota, one would expect their productivity to be greater than continuing vessels in order to for them to purchase quota and still be profitable. Essentially, the ITQ is creating an additional entry barrier, and we would expect only more productive vessels to be able to overcome that barrier. Alternatively, continuing vessels may need to increase their productivity to discourage entry and keep existing contracts with processors.

Although ITQs are viewed as a tool that can move management to a market based system, there are still factors which limit future productivity gains. Beginning on the output side, potential increases in output for vessels are limited because regulators set the overall catch that can be taken from the resource. Thus, there is an upper bound on output expansion for both vessels and the fleet. Some externalities which existed prior to an ITQ program will still exist after an ITQ program begins. For example, fishing location choice and potential output from any place in the ocean is not independent of other vessels fishing activity. For a sessile species such as surfclams and ocean quahogs, ITQs tied to specific fishing locations may provide more options for vessels. Prices for trades of ITQs between different areas would likely account for the increased cost of harvesting quota from more distant regions.

5. Summary and conclusions

A productivity index was developed which measures productivity in any year as the ratio of an output index to an input index. This was applied to a fleet of fishing vessels operating in the Mid-Atlantic surfclam and ocean quahog ITQ fishery, both before and after implementation of the ITQ management system. An aggregate yearly index for all vessels was then constructed based on the denominator rule, and then adjusted by a biomass index to yield a biomass adjusted productivity index. Because changing resource conditions can influence output, it is important to separate those impacts from productivity change being driven by factors which are internal to the vessel operations. Based on the biomass adjusted Färe–Primont index, productivity increased post-ITQ.

An advantage of the Färe–Primont index is that it does not require balanced panel data, allowing one to examine productivity for firms which don't appear in consecutive years. This also adds flexibility as both firm level, and industry level changes in productivity can be examined. Often, the number of vessels in specific categories was low, and the ability to then examine results at the vessel level gave further insight into trends. For this fleet, productivity change in any year is being driven by survivor vessels, rather than new vessels entering the fishery. However, on average entering vessels were as productive as continuing vessels after ITQs were implemented. Exiting vessels on average were generally less productive both before and after the ITQ program was implemented.

There needs to be further research conducted on how to incorporate biomass change in index numbers. It is clear that biomass steadily declined during the study time period. Results showing flat or slightly declining unadjusted productivity, along with a declining biomass index implies to managers that the fleet has made productivity gains post-ITQ. The ability to decouple the productivity gains due to improved input use, or technological change, from that caused by changing resource conditions is important information for managers. This is particularly true for fish stocks that are being rebuilt through effort controls because productivity gains by the fleet can negate management measures meant to limit output.

A final factor which also may be limiting productivity gains is the industrial structure in which the fleet operates. Vessels are now increasingly part of vertically integrated companies, and productivity gains at the harvest sector may be less important. The profit center for the processing firm is likely to be at the corporate, or plant level. Increased productivity for the fishing vessels may be of little concern. The surfclam and ocean quahog fleet may still be evolving to reach an equilibrium point, with further exit, and new capital replacing old technologies and capital. This is a rich topic for further research as it may help inform managers about how post ITQ fishing fleets fully evolve.

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