Productivity Change under an Individual Transferable Quota Management System

John B. Walden, James E. Kirkley, Rolf Färe, and Philip Logan

This study examines productivity change in the Mid-Atlantic surfclam and ocean quahog fishery, which has been managed since 1990 using Individual Transferable Quotas (ITQ). Productivity change is estimated through a Malmquist index from 1981–2008, capturing change before and after implementation of the quota system. We then decompose the index to examine changes in technical efficiency, scale efficiency, and technical change. Our findings indicate that the ITQ system has not sustained gains in vessel productivity. These results are thought to be driven by spatial changes in biomass and the inability to access more productive fishing grounds.

Key words: productivity change, individual transferable quotas.

JEL Codes: D24, Q22.

Introduction

Fisheries are common pool resources and the difficulties associated with managing these resources in a biologically and economically sustainable manner are well-documented (Hannesson 2010). One approach to managing fisheries is to set a total allowable catch, and then divide the catch among participants so that each is free to harvest their share of the total using whatever means they deem best. This type of management approach is known as an individual transferable quota system (ITQ), and has existed for over 20 years in fisheries worldwide. Under an ITQ system, vessels with the lowest harvesting costs can expand their catch by buying or leasing shares from other, higher-cost vessels, leading to lower overall harvest costs and more efficient outcomes for society. Wesney (1989) summarized this view when he stated that, "From a theoretical point of view, the method of controlling total catch through a total quota or total allowable catch, allocated among fishermen as individual transferable quotas (ITQs) is preferred as most likely to promote economic efficiency." This has its roots in welfare theorems that relate (Pareto) efficiency to competition (market equilibrium).

Slowly, ITQs have been adopted worldwide, and studies examining change in economic performance metrics for fishing vessels after implementing ITQs have emerged. A move to this type of market-based management system provides policy-makers with a type of natural experiment where the predicted results of increased efficiency can be tested (Brandt 2003). Although there is generally no control group because vessels without an ITQ allocation cannot land fish, readily-available micro-level data can inform researchers about trends in productivity, efficiency and capacity utilization for survivor vessels (i.e., those that operated both before and after ITQ implementation), as well as entering and exiting vessels. The extent to which these economic performance metrics change with shifts in management methods can provide important insights for future management actions.

This article examines long run changes in vessel productivity in the mid-Atlantic surfclam and ocean quahog fishery by constructing the Malmquist index (MI) for vessels both pre- and post-ITQ. Because this is the longest administered ITQ program in the United States, productivity and efficiency changes in this fishery post-ITQ have been examined

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previously, but not for as long of a time period as this study (1981–2008). Weninger (1998) presented a method for estimating efficiency gains post-ITQ in the face of incomplete fleet restructuring, and found that eliminating redundant harvesting capital and realizing scale economies were important sources of efficiency gain. Weninger's study predicted that the Mid-Atlantic surfclam and ocean quahog fleet would eventually contract to 21–25 vessels operating at a cost-efficient output scale. Weninger and Strand (2003) showed that pre-ITQ regulations in the surfclam and ocean quahog fisheries encouraged diversified production when diseconomies of scope would have favored specialized production. Brandt (2003, 2007) examined the role of strategic behavior prior to implementing the ITQ program, and found that vessel operators have incentives to behave strategically and increase their efficiency pre-ITQ implementation in order to receive a larger quota allocation. It is unclear whether these efficiency gains can be maintained post-ITQ, but one would expect quota to be traded from less efficient vessels to more efficient vessels (Weninger 2008).

Insights into changes in economic performance that occur post-ITQ have been undertaken worldwide. DuPont et al. (2002) studied capacity utilization and excess capacity in the Nova Scotian mobile gear fishery, and found that individual vessel capacity utilization changed very little after adopting ITQs, but that excess capacity in aggregate declined, and that a more heterogeneous fleet emerged in terms of capacity. Fox et al. (2003) examined the change in components of profitability, including productivity, after ITQs were implemented in the British Columbia halibut fishery; they found that for vessels in this fishery, the greatest benefit associated with a shift to individual harvesting rights was an increase in output prices, which they attribute to a longer fishing season. Thus, gains from privatization were on the revenue side, as opposed to cost savings. In the Nova Scotian mobile gear fishery, Dupont et al. (2005) found that short-run gains associated with ITQs were largely from higher prices, supporting the view that ITQ programs encourage better quality catches that lead to higher prices. Fox et al. (2006) showed positive changes in prices and vessel productivity in the southeast Australian trawl fishery after implementing a vessel buyback, coupled with the establishment of a brokerage service that allowed quota trading. Sharp and Batstone (2007) examined the Australian rock lobster fishery after adopting ITQs and found average landings and landings per labor input both increasing, along with technical change.

Our study is the first that we are aware of that fully decomposes productivity change for a group of fishing vessels under an ITQ system over an extended time period (28 years), including years from both pre- and post-ITQ eras. Therefore, this paper contributes important insights about firm-level productivity change under two different management regimes over a long time horizon (28 years). We begin with a brief overview of the surfclam and ocean quahog fleet, both before and after implementing the ITQ system. This is followed by a discussion of productivity change, which includes the MI, followed by the decomposition of the index into various components that measure efficiency, scale and technical change. We then describe the data used in constructing the MI, and present our findings. We follow this with a comparison of productivity between continuing, entering, and exiting vessels during three-year time periods, both before and after implementing ITQ. Finally, we discuss the results and offer several explanations for the changes observed in the fishery.

The Surfclam and Ocean Quahog ITQ Fishery

Surfclams and ocean quahogs are bivalve mollusks distributed in nearshore and offshore waters along the mid-Atlantic coast of the United States that are commercially harvested by dredge vessels. Surfclams are generally located in shallower waters than ocean quahogs, but both mollusks are sold to processors, who transform them into breaded clam strips, soups and chowders. Both species are managed by the Mid-Atlantic Fishery Management Council through a plan first implemented in September 1977, and each has its own annual catch quota (TAC). The U.S. stock resource is almost entirely within the Exclusive Economic Zone (EEZ, ranging from 3–200 miles from shore), outside of state waters and at depths between 20–80 meters. The notable exception is fishable concentrations of ocean quahogs in state waters off the coast of Maine. Almost half of the current surfclam stock is found on Georges Bank (GBK), which has not been fished since 1989 due to paralytic shellfish poisoning (PSP) toxins found in surfclam meats. State water fisheries are a small part of the overall fishery, with only about 10% of the total surfclam landings coming from state waters,

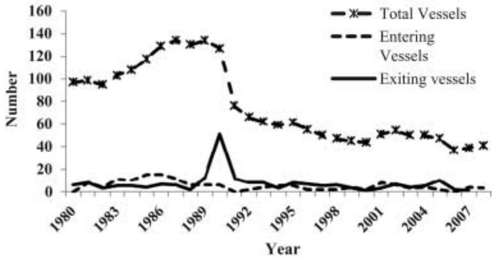

Figure 1. Total, entering and exiting surfclam and ocean quahog vessels operating in the Mid-Atlantic area, 1980–2008

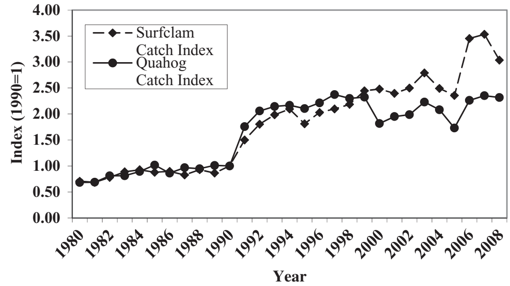

Figure 2. Catch per vessel index (Base = 1990) for vessels participating in the surfclam and ocean quahog ITQ fishery, 1980–2008

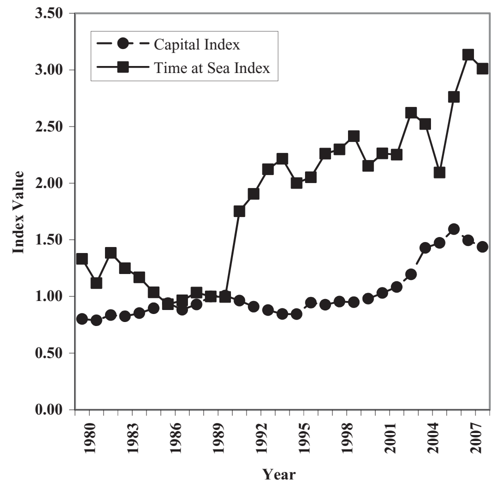

Figure 3. Catch per vessel index (Base = 1990) for vessels participating in the surfclam and ocean quahog ITQ fishery, 1980–2008

and about 3% of the overall quahog landings coming from Maine state waters. The Maine resource is harvested by smaller vessels, and the product goes to a fresh market, which is a different market than that for quahogs harvested by vessels fishing in the EEZ.

From 1979–1989, vessels fishing for these two species in the EEZ were regulated through a command and control system that limited the amount of time a vessel could fish in a calendar quarter. During this 11-year period, the average allowable fishing time per vessel declined from 36 hours per week in 1979 to six hours per week in 1984 (Brandt 2005). Between 1980 and 1989 (the last year before the ITQ regime was implemented), fishing restrictions reduced time at sea by 57% per vessel for surfclam vessels. In the years prior to implementation of the ITQ, there was an influx of vessels, as owners sought to build fishing history so that they would receive a share of the quota. Quota shares were to be given away free of charge, based partly on catch history.

Subsequent to the ITQ system being enacted in 1990, a large reduction in the number of surfclam and ocean quahog vessels occurred, followed by further declines during the next 18 years (figure 1). Thus, it would seem that vessel productivity should have steadily increased over time as the annual quotas were harvested by fewer vessels. 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.[1] Once a fleet reaches its long-run equilibrium structure, the remaining vessels should be the most efficient (Brandt 2007).

The average per-vessel catch of both surfclams and ocean quahogs increased markedly after ITQs were implemented (figure 2). In 2008, the average surfclam catch per vessel was triple that of 1990, and the average ocean quahog catch was more than double. Changes also occurred in the capital employed and the time a vessel was deployed at sea. Based on a composite capital input index constructed from the product of vessel gross tonnage, horsepower and length, capital increased until 1990, declined from 1991–1994, and subsequently increased (figure 3). A similar index for time at sea declined prior to 1990, but has subsequently shown an increasing trend (figure 3).

Assessing Productivity Change

Productivity is a key economic indicator at the household, firm, industry and national levels, and is a critical factor in economic growth

[1] This assumes price-taking behavior in the input and output markets.

(Färe, Grosskopf, and Margaritis 2008). Productivity measures the total output given the input bundle used to generate the output. Total factor productivity (TFP), which is by definition the most general measure of productivity change (Balk 2003), can be measured at the aggregate industry level, or at the firm level (Balk and Hoogenboom-Spijker 2003). Two main approaches are used to measure productivity. Traditional productivity indexes such as Fisher, Laspeyres, Paasche, and Törnqvist, use price information to aggregate outputs and inputs. Revenues approximate total output and costs approximate total inputs (Färe, Grosskopf and Margaritis 2008). These are difficult to construct for fishing vessels because cost data are often not available, or are very limited. The second approach avoids the problem of no cost data by using aggregators based directly on the technology and input and output quantities through optimization. In the case of multiple outputs and inputs, the distance function can be used; distance functions are quite useful because price information is not needed to aggregate outputs and inputs, and because they are themselves useful efficiency measures (Färe, Grosskopf and Margaritis 2008). Among the economic aggregators used to measure productivity change, the MI introduced by Caves, Christensen, and Diewert (1982) has been extensively applied, and has generated a vast body of literature (Färe, Grosskopf and Margaritis 2008). The Malmquist output-oriented productivity index is the ratio of two output distance functions. Färe et al. (1989) demonstrated how the Shephard (1970) output distance function could be used to construct the index. In the twenty-plus years since the work of Färe at al., studies using directional distance functions, along with hyperbolic efficiency methods, have also been used to assess firm-level productivity change. These approaches have led to other measures of productivity change using ratio-based indices, such as the Hicks-Moorsteen productivity index, or difference-based approaches such as the Luenberger productivity indicator. In particular, the Luenberger indicator, which is based on differences in outputs and inputs, has several appealing properties.

Here, we choose to use an index-based approach using ratios, rather than an indicator based on differences, and the MI based on radial distance functions proved advantageous for our study. A distance function approach was preferred because the available data for the time period consisted of input and output quantities, with no corresponding input prices. Additionally, output prices may not reflect true market prices, because generally vessels deliver their product to specific processors based on contractual arrangements. The lack of cost data and questionable market price data is found worldwide in fisheries, and has made the MI a natural choice for studying productivity change. Examples of studies where the MI has been constructed to study productivity change for fishing fleets includes work by Hoff (2006) on a North Sea purse seine fleet, and Oliveira et al. (2009), who constructed the MI for an artisanal fishing fleet in Portugal.

Within the choice of distance functions, the radial measure, which is the basis of the MI, preserves the same output mix, although we also note that using a directional distance function with the directional vector set equal to the observed output will preserve symmetry with the traditional distance function (Färe and Grosskopf 2000). This is important because one common trait among fishing vessels is that in a multi-output framework, many vessels have zero valued outputs for one or more outputs. A radial measure will ensure that those outputs stay zero. The radial measure is also somewhat easier to interpret when different units of measurement are used for output quantities, as all outputs are expanded by the same percentage. An additive measure does not have this property. For example, if landings were bushels of clams and pounds of finfish, the additive model provides a solution which is difficult to interpret without converting units of one product to units of the other.

Change in total factor productivity (TFP) between two periods is defined by:

$$(1) \qquad TFP = \frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}$$

where D_o^t is an output (o) distance function, t is time period t, x^t is a vector of inputs corresponding to time period t, and y^t is a vector of outputs produced in time period t. Given that the technology can be relative to time t or $t+1$, Färe et al. (1989) recommend calculating the Malmquist index as a geometric mean of the two periods as follows:

$$(2) \qquad M(x^{t+1}, y^{t+1}, x^t, y^t) = \left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)^{1/2}.$$

The MI can then be further decomposed into an efficiency change (EC) component, which identifies movement toward the frontier, and a technical change (TC) component, which identifies shifts in the frontier (Färe et al. 1989). Most constructions of the MI have used a cone (benchmark) technology, which estimates the frontiers relative to constant returns to scale technology.[2] Alternative decompositions have used the best practice frontier, which estimates efficiency change and technical change relative to a variable returns-to-scale technology (Färe, Grosskopf and Margaritis 2008). We used the approach of Färe and Grosskopf (1996) and Färe, Grosskopf and Margaritis (2008), and decomposed the MI into an efficiency change component (based on variable returns to scale), a scale efficiency change, and a technology change (based on constant returns to scale). We further decomposed the technology change into three categories: input biased technical change, output biased technical change, and a magnitude component.

The MI was decomposed into efficiency change, scale change, and technical change as follows:

$$(3)\qquad \mathrm{MI} = \mathrm{EC_v}{}^*\mathrm{SC}^*\mathrm{TC_c}$$

where a "v" subscript denotes variable returns to scale, a "c" subscript denotes constant returns to scale, and SC means scale change. In terms of the distance functions, the terms $\mathrm{EC_v}$, SC, and $\mathrm{TC_c}$ are defined as:

$$(4)\qquad EC_v = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)}$$

$$(5)\qquad SC = \frac{S^{t+1}(x^{t+1}, y^{t+1})}{S^t(x^t, y^t)} = \left[\frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_v^{t+1}(x^{t+1}, y^{t+1})} \Big/ \frac{D_c^t(x^t, y^t)}{D_v^t(x^t, y^t)}\right]$$

$$(6)\qquad TC_c = \left(\frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^{t+1}, y^{t+1})}\,\frac{D_c^t(x^t, y^t)}{D_c^{t+1}(x^t, y^t)}\right)^{1/2}.$$

A value greater than one for overall MI indicates an improvement in productivity, while a value less than one means that productivity has declined. This also applies to the individual components which make up the index; for example, a value greater than one for the efficiency component means that efficiency has improved.

Further decomposition of the technical change component resulted in an input biased element ($IBTECH$), an output biased element ($OBTECH$), and a magnitude element ($MATECH$). Output biased technical change reveals how outputs change between year t and $t+1$ given year $t+1$ inputs. Input biased technical change indicates how input usage changes between years t and $t+1$ with year t outputs. The decomposition and output distance functions used in the calculations were (Färe and Grosskopf 1996):

$$(7)\qquad TC_c = OBTECH^*IBTECH\ {}^*MATECH$$

$$(8)\qquad OBTECH = \left[\frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^{t+1}, y^{t+1})}\,\frac{D_c^{t+1}(x^{t+1}, y^t)}{D_c^t(x^{t+1}, y^t)}\right]^{1/2}$$

$$(9)\qquad IBTECH = \left[\frac{D_c^{t+1}(x^t, y^t)}{D_c^t(x^t, y^t)}\,\frac{D_c^t(x^{t+1}, y^t)}{D_c^{t+1}(x^{t+1}, y^t)}\right]^{1/2}$$

$$(10)\qquad MATECH = \frac{D_c^t(x^t, y^t)}{D_c^{t+1}(x^t, y^t)}.$$

If both the output biased and input biased technical change elements equal one, technical change is considered to be Hicks-neutral (Managi and Karemera 2004).

Various approaches can be used to estimate the required distance functions. A thorough discussion of the numerous approaches which could be used to estimate the corresponding output distance functions, as well as changes in productivity, technical efficiency, and scale, can be found in Coelli et al. (2005). In our study, data envelopment analysis (DEA) was used to estimate these functions, and strong disposability of outputs and inputs was assumed. The time period covered in the analysis was 1981–2008, which encompassed years both before and after implementing ITQs in the surfclam and ocean quahog fishery.

Data

The MI was constructed from data obtained from vessel logbooks for the years 1980–2008,

[2] We use Data Envelopment Analysis to construct our distance functions. One potential problem in a cross-period distance function analysis using a linear programming routine is that an infeasible solution can occur. However, if using a constant returns to scale model, this cannot happen.

vessel permit files, and from stock assessments. The inputs used in the model were the following: vessel length, gross tonnage, horsepower, time at sea, surfclam biomass, and ocean quahog biomass. Outputs were bushels of surfclams and bushels of ocean quahogs landed. Estimates of fishable biomass measured in metric tons from 1980–2008 for both species were derived from periodic stock assessments (MAFMC 2010). The surfclam assessment indicates that total biomass increased from 1981 until the late 1990s, and then declined to about the same level as in 1981. Fishing mortality contributed only modestly to the decline, which was mostly due to lower reproduction. The ocean quahog population is a relatively unproductive stock that is being fished down from what is considered its virgin state.

Incorporating biomass into productivity estimates of fishing vessels dates back to Squires (1987, 1992). Studies by Jin et al. (2002), Felthoven, and Morrison-Paul (2004), Hannesson (2007), Brandt (2007), Squires, Reid and Jeon (2008), Felthoven, Morrison-Paul and Torres (2009), and Eggert and Tveterås (2013) have all incorporated explicit measures of fishing stock biomass. The biomass of each species is outside the control of the firm, so including these inputs in a DEA context is not typical. However, non-discretionary factors can be included in a DEA model and a free disposability assumption can be made if an increase in the favorable factor does not reduce output (Ray 2004). We believe that this describes fishing vessels in general, as higher biomass levels typically lead to higher catches.

Since we calculated yearly index values using pairs of successive years, vessels had to fish in both years to derive the cross-period distance functions. As a consequence, only vessels which fished in two successive years were included in the analysis.[3] For example, vessels had to fish in both 1985 and 1986 to be included in the productivity change calculation for 1986. We also only included vessels fishing in federal waters in the Mid-Atlantic region, and excluded those fishing in state waters, or on Georges Bank. As noted previously, vessels fishing in state waters contribute a very small amount to overall landings, and the Georges Bank region has been closed to fishing since 1990. Before the index numbers were calculated, we compared the data on vessel inputs and outputs for all vessels in each year with vessels which were part of the annual data that was subsequently used to construct the index. A Kruskal-Wallis test was used to detect any significant differences (.05 level) in input usage and outputs produced (tables 1 and 2). The only year where a difference was detected was 1990, where there was a large difference in the number of vessels in the two groups (127 and 75). The ITQ program was enacted in September 1990, and consolidation began to occur shortly thereafter. Vessels that remained in the fishery in 1991 and which also fished in 1990, fished significantly longer and landed more surfclams and quahogs than vessels that fished only in 1990. Given the transition to an ITQ system where vessels are no longer restricted in fishing time, this is a logical finding. After ITQ implementation, vessels that remained in the fishery increased both their fishing time and landings. Apart from 1990, no significant differences were detected in any of the variables between the annual data sets. Thus, we believe that the vessels used to construct the MI were representative of the fleet as a whole.

Results

The MI and corresponding decompositions were calculated for each year from 1981–2008 (table 3). These values were then used to construct a chain index for the entire time period, where the value in time $t+1$ equals the value of the index in time $t+1$ multiplied by the value in time t. In the early 1980s, productivity rose sharply until 1985, and then leveled off, or declined slightly until 1990 (figure 4). After implementing ITQ in 1990, productivity again increased until 1994. Subsequently, productivity has trended downward. This productivity pattern is similar to that reported by Brandt (2003), who found a large increase in productivity for surfclam and ocean quahog vessels from 1980–1984, a slowing from 1985–1989, and an increase from 1990–1995. Brandt (2003) noted that vessels may have been strategically trying to increase their catches so they would be granted a larger portion of the eventual quota that was to be distributed to vessels during the 1985–1989 transition period. This may have contributed to a slowdown in productivity growth. Our post-1994 results are similar to the findings reported in the latest quota specification document (MAFMC 2010), which indicate a partial

[3] An alternative approach would have been to insert mean values for vessels in the year where they did not appear in the data.

Table 1. Mean Input Usage for all Vessels Operating in a Year and for Vessels Used to Construct the Malmquist Index, 1981–2007

Year	Vessels	Number	Length Mean	Tons Mean	Horsepower Mean	Time (Hours) Mean
1981	All	99	84.1	119.6	500.3	1002.5
	Index	91	86.2	124.7	517.8	1067.3
1982	All	95	86.1	124.3	516.7	1241
	Index	92	86.7	125.5	519.5	1272
1983	All	103	86.3	126.5	514.3	1119.4
	Index	98	86.3	124.9	508.3	1149.6
1984	All	108	85.9	126.4	514.6	1047.3
	Index	103	86.7	128.2	523.8	1088.5
1985	All	118	86.9	128.7	536.6	928.9
	Index	114	87	129.2	535.4	940.6
1986	All	129	88	131.6	553.4	833.7
	Index	122	87.2	130.2	556.7	855.9
1987	All	134	86.1	127.5	551.7	865.2
	Index	128	86.6	128.2	557.8	892.4
1988	All	130	87.1	128.1	565.4	927.4
	Index	128	87.3	129	569.3	940.6
1989	All	134	87.1	128.1	587.4	896.4
	Index	119	87.3	129	599.9	915.6
1990	All	127	88.7	136.9	598.7	891.9
	Index	75	89.3	137.2	615.9	1293.3*
1991	All	76	89.5	136.9	617.4	1569.5
	Index	64	88.7	138.2	615.5	1789.6
1992	All	66	88.5	138.7	620.9	1707.2
	Index	58	87.6	138.1	616.1	1853.9
1993	All	62	87.3	138.3	614.4	1902.1
	Index	54	88.1	139.7	626.1	2090.7
1994	All	59	84.8	138.6	609	1984.6
	Index	56	85.5	140	616.8	2086.6
1995	All	59	84	138.6	615.3	1792.7
	Index	56	85.8	140.6	632.3	2005.8
1996	All	55	85.7	142.6	655.6	1838.8
	Index	48	86.8	141.8	654.4	2049.9
1997	All	50	86.5	141.7	645.2	2025.1
	Index	45	87.8	142.5	670.1	2219
1998	All	47	87	141.7	658.7	2058.7
	Index	41	88.4	145.7	678	2110.5
1999	All	45	86.4	142	645.6	2163.9
	Index	42	88	145.1	669.5	2308.9
2000	All	44	87.3	144.6	662.2	1928.2
	Index	43	87.6	144.1	661.3	1929.1
2001	All	51	86.9	148.6	637.4	2027.4
	Index	48	87.9	151.5	641.8	2149.2
2002	All	54	88.3	152.7	657.1	2017.5
	Index	47	90.1	157.1	694.2	2172.9
2003	All	50	91.1	158.1	696.6	2348.5
	Index	46	92.2	159.1	717.2	2498.6
2004	All	50	94.6	161.7	766	2259.6
	Index	45	94.5	162.8	788.6	2326.7
2005	All	47	94.6	160.8	782.1	1875.9
	Index	37	97	164.1	836.6	2063
2006	All	37	96.8	164.1	867.5	2474.2
	Index	35	96.2	155.1	864.8	2565.9
2007	All	39	94.2	153.3	833.3	2809.2
	Index	38	94.4	153.3	843.4	2797

*Denotes significant difference at the .05 level based on a Krukal-Wallis test.

Table 2. Mean Landings for all Vessels Operating in a Year and for Vessels Used to Construct the Malmquist Index, 1980–2007

			Surfclams (Bushels)	Quahogs (Bushels)
Year	Vessels	Number	Mean	Mean
1981	All	99	15,763	24,781
	Index	91	16,981	26,756
1982	All	95	17,952	29,271
	Index	92	18,450	29,951
1983	All	103	20,457	29,262
	Index	98	20,872	30,069
1984	All	108	21,352	32,226
	Index	103	22,175	33,580
1985	All	118	20,217	36,686
	Index	114	20,510	36,992
1986	All	129	20,625	31,087
	Index	122	21,217	32,684
1987	All	134	19,022	34,893
	Index	128	19,591	36,339
1988	All	130	21,384	34,159
	Index	128	21,711	34,678
1989	All	134	19,885	36,422
	Index	119	20,911	39,329
1990	All	127	23,019	36,043
	Index	75	29,063*	58,264*
1991	All	76	34,527	63,345
	Index	64	37,359	75,194
1992	All	66	41,521	74,184
	Index	58	45,406	80,544
1993	All	62	45,688	77,350
	Index	54	51,014	84,277
1994	All	59	48,231	78,169
	Index	56	50,637	82,357
1995	All	59	41,726	75,874
	Index	56	47,382	86,050
1996	All	55	46,715	79,812
	Index	48	51,468	90,774
1997	All	50	48,271	85,581
	Index	45	53,062	93,354
1998	All	47	50,311	82,952
	Index	41	54,855	80,626
1999	All	45	56,328	83,784
	Index	42	59,851	89,769
2000	All	44	57,089	65,477
	Index	43	58,417	65,497
2001	All	51	55,161	70,318
	Index	48	58,301	74,685
2002	All	54	57,543	71,637
	Index	47	63,733	76,624
2003	All	50	64,214	80,359
	Index	46	66,318	87,386
2004	All	50	57,386	75,060
	Index	45	61,216	75,882
2005	All	47	54,263	62,386
	Index	37	59,478	71,629
2006	All	37	79,484	81,558
	Index	35	83,859	84,073
2007	All	39	81,328	84,807
	Index	38	80,644	87,039

*Denotes significant difference at the .05 level based on a Krukal-Wallis test.

productivity measure of landings per unit effort declining almost 10% per year between 2000 and 2009.

We then examined productivity trends, both pre- and post-ITQ implementation by converting the chain index to a base year index, with the base year set to 1989, the year before ITQ implementation. We did the same for the decomposition of the MI into efficiency, scale efficiency and technical change components (figure 5). The time trends of the efficiency and scale efficiency indices are both similar to the MI, exhibiting the following: (a) a rapid increase in productivity until 1985; (b) a leveling off until 1990, when ITQs were implemented; (c) increases until 1994; and (d) subsequent declines. Both the efficiency change index and the scale change index have trended downward after implementing the ITQ program. The technical change index shows a different pattern; rapid increases occurred until 1992, the index remained relatively flat until 2000, and then declined, except for sharp upward spikes in 2001 and 2006. This pattern suggests that shifts in the technical change component kept productivity from declining further.

The decomposition of the technical change component into three elements (input biased technical change; output biased technical change; and magnitude change) revealed that output biased technical change has been driving the technical change component (figure 6). The output bias element shows an increasing trend until 2004, and a declining trend thereafter. The input bias element shows a steady decline from 1982–2005, and a flat trend afterwards. This indicates that technical change is non-Hicks-neutral.

Because the output biased technical change element influences the upward trend in technical change, we investigated various factors which might be associated with the trend. Output biased change is based on the square root of two Malmquist output indices, one using period t technology, and one using period $t+1$ technology (Färe and Grosskopf 1996). The outputs are either from period t or period $t+1$, but the inputs are from period $t+1$. For the measure to recognize bias, the output mixes must be distinct in each period (Färe and Grosskopf 1996).

To examine how output mixes might be changing between time periods and influencing the frontier, an output mix index was derived using the ratio of surfclam to quahog production per vessel in each year, divided by the ratio of surfclam to quahog production in 1989, the

Table 3. Geometric Means of the Malmquist Index and Component Parts for the Surfclam and Ocean Quahog Fleet, 1981–2008

Year	Malmquist Index	Efficiency Change	Scale Efficiency Change	Technical Change	Technical Change Components: Output Biased	Technical Change Components: Input Biased	Magnitude Component
1981	1.12	0.93	1.04	1.17	1.17	0.89	1.12
1982	1.01	1.04	0.98	0.98	0.94	1.17	0.90
1983	1.30	1.29	0.98	1.03	1.03	0.99	1.01
1984	1.21	1.00	1.14	1.06	1.13	0.96	0.98
1985	1.10	0.98	1.04	1.08	1.17	0.93	0.99
1986	1.00	1.04	1.00	0.96	1.06	0.94	0.96
1987	0.97	1.03	1.01	0.93	1.03	0.98	0.92
1988	1.01	1.01	0.94	1.07	1.07	0.95	1.05
1989	1.00	1.00	1.00	0.99	1.08	0.95	0.97
1990	1.06	1.00	0.90	1.18	1.09	0.92	1.17
1991	1.00	1.01	0.94	1.06	1.10	0.95	1.02
1992	1.08	0.92	0.97	1.21	1.21	0.85	1.18
1993	1.03	1.08	1.02	0.93	1.09	0.94	0.91
1994	1.01	0.97	1.04	1.00	1.08	0.94	0.98
1995	0.95	0.96	0.99	1.00	1.12	0.91	0.98
1996	0.98	1.03	0.97	0.99	1.10	0.93	0.97
1997	0.91	0.94	0.95	1.01	1.03	0.98	1.00
1998	1.02	1.03	0.99	0.99	1.07	0.94	0.99
1999	1.07	1.02	1.03	1.02	0.96	1.07	1.00
2000	0.95	0.98	0.98	0.99	1.10	0.92	0.98
2001	0.99	0.91	1.01	1.08	0.90	1.15	1.05
2002	0.99	1.02	1.02	0.95	1.17	0.86	0.95
2003	0.93	0.98	0.94	1.01	1.04	0.97	1.00
2004	1.02	0.99	1.08	0.95	1.11	0.91	0.94
2005	0.87	1.07	0.84	0.98	1.32	0.77	0.96
2006	1.08	0.92	0.99	1.18	0.94	1.11	1.14
2007	1.00	1.02	1.04	0.95	0.92	1.10	0.94
2008	0.94	1.00	0.98	0.95	0.98	1.02	0.95

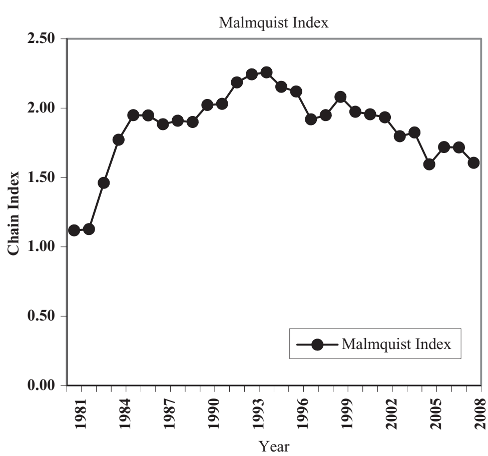

Figure 4. The malmquist index for the surfclam and ocean quahog fleet, 1981–2008 (Chain Index)

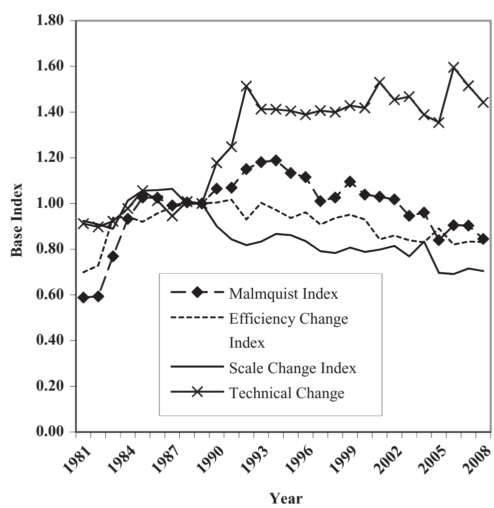

Figure 5. The malmquist index, efficiency change, scale change, and technical change, 1981–2008 (base index 1989)

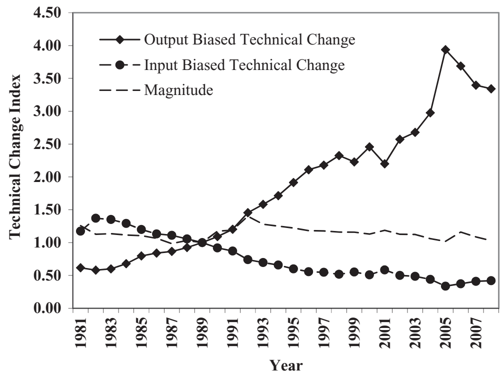

Figure 6. Output biased technical change, input biased technical change, and magnitude component (base year index 1989)

year before ITQ implementation:

$$(11)\quad \frac{y_2^t}{y_1^t} \Big/ \frac{y_2^{1989}}{y_1^{1989}}$$

where y_2 is surfclams and y_1 is ocean quahogs.

This index used a base time period of 1989 and therefore could be directly compared with the output biased technical change index, which also used a base period of 1989. If the output mix index is greater than one, a shift has occurred toward surfclams relative to quahogs compared to the product mix in 1989. Conversely, an index value of less than one indicates a shift toward ocean quahogs (y_1) relative to surfclams compared to the output mix in 1989. All annual output mix indices from 1981 onwards, except those for 1990 and 1991 (and the 1989 base year), are greater than one (figure 7), indicating a greater output reliance on surfclams compared to 1989. Since 1990, the trend in the output mix index has been similar to the output biased technical change index, although the absolute values of the mix index are lower.

To further examine this trend, vessels' output mix between 1980 and 2008 was examined for single output production (i.e. only surfclams or ocean quahogs produced), or mixed production where both species were harvested. Until 1992, the fleet was dominated by vessels that harvested surfclams, or landed surfclams and ocean quahogs (figure 8); very few vessels harvested only ocean quahogs. Beginning in 1992, most vessels fished for surfclams or ocean quahogs, but not both. During the period of most severe harvest restrictions (1988–1989), only 9.2% of vessels specialized in harvesting just one of the two species in any calendar year quarter, while in the 1993–1994 post-ITQ period, 26.5% of the vessels specialized (Weninger and Strand 2003). This trend toward specialization has continued and, in 2008, 84% of the vessels harvested only surfclams or only ocean quahogs. This shift is likely due to a combination of differences in product value and biomass. The value of ocean quahogs is roughly half that of surfclams (MAFMC 2010). In 2008, the reported price for surfclams ranged between \$10.50 and \$13.50 per bushel, while the price for ocean quahogs ranged between \$6.50 and \$7.00 per bushel. In terms of biomass, surfclams increased to peak levels in the 1990s before recently declining. Since 1990, an increasing portion of both the surfclam and ocean quahog resources has been located on

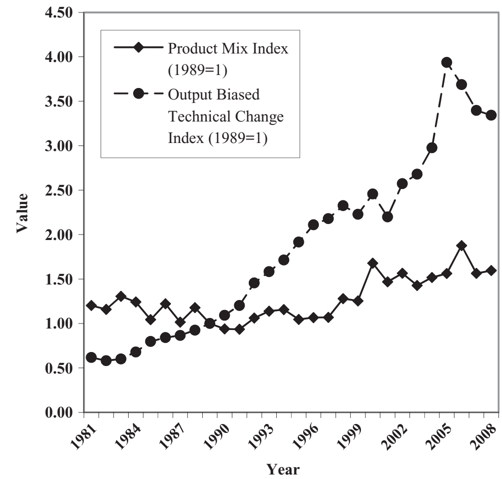

Figure 7. Output biased technical change index and product mix index (base year 1989)

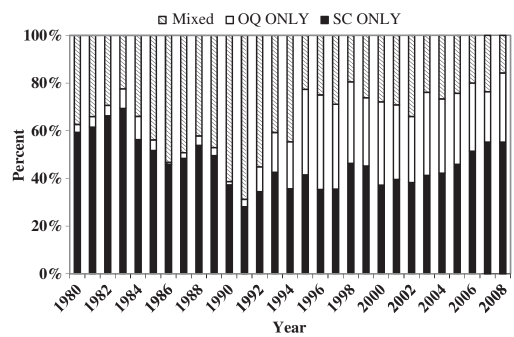

Figure 8. Percentage of vessels that produce surfclams only, ocean quahogs only, and both products, 1980–2008

Georges Bank, which was closed in 1990 due to paralytic shellfish poisoning. This has led to increasing reliance on known fishing locations outside the Georges Bank region. We believe this is an important factor in the observed productivity trends and will be discussed further in the next section.

A similar question can be asked of the input biased technical change component; that is, why is it trending downward? The input biased technical change component measures the shift in technology given input usage between two different periods. When constructing the measure, if input usage doesn't change between period t and $t+1$, $IBTECH$ will equal one, since outputs are taken from period t for all four distance functions used in the index. Since $IBTECH$ trends downward when put in a chain index, it indicates that the mix of inputs is changing. This can be investigated in a similar manner to the output index constructed earlier, that is, by separating inputs into a capital component and a variable input component. For our vessels, time at sea is the single variable input used, while vessel capital components include length, horsepower, and gross tonnage.

In order to examine the capital-effort ratio, we constructed an index which was similar to the output index shown in the prior section. The index is:

$$(12) \qquad \frac{K^t}{E^t} \Big/ \frac{K^{1989}}{E^{1989}}$$

where K is the capital index and E is the effort index. This can be simplified further, so that the capital and effort component can be examined separately:

$$(13) \qquad \frac{K^t}{K^{1989}} * \frac{E^{1989}}{E^t}.$$

A ratio greater than one for the capital component (K) indicates increasing capital relative to 1989 levels, while a ratio of less than one indicates less capital. For the effort component, a ratio of less than one means greater time at sea compared to 1989 levels, while a ratio of greater than one means less time at sea.

Plotting these two indices, along with the $IBTECH$, helps explain the trends (figure 9). $IBTECH$ peaks in 1982, and then begins a slow gradual decline. Both the capital and the effort index are below 1.0 for much of the pre-ITQ time period, but generally show an upward trend. The rise in the capital index

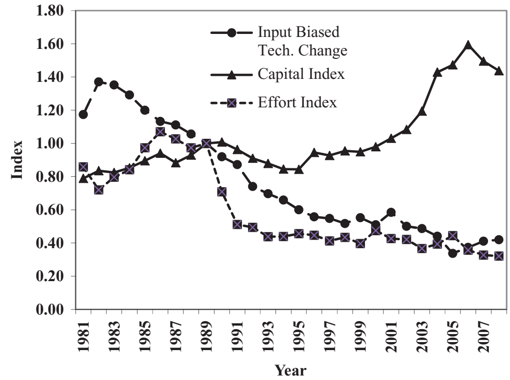

Figure 9. Input biased technical change, capital index, and effort index, 1981–2008

indicates increasing capital stock relative to 1989 levels as vessels enter and attempt to secure a share of the approaching ITQ. Conversely, the rising effort index means days at sea are declining relative to 1989 levels. Since this was a period of effort control, there is no real opportunity for vessels to substitute effort for capital. Post-ITQ, effort increased substantially, and $IBTECH$ and the effort index exhibit the same pattern. This indicates a bias toward increased variable input usage (in this case time at sea) over increasing capital. Beginning in 2001, the capital index started to rise dramatically as new vessels entered the fishery. Given that much of the capital pre-ITQ is used post-ITQ, this pattern makes sense. Management had shifted from input controls to output controls, and vessels were trying to increase their profitability through increased landings. Initially it was less costly to do so through increased fishing time using existing capital than replacing capital stock. Over time, capital was slowly replaced, and in this fishery newer, bigger vessels entered.

A final question is how productivity differs for vessels entering, exiting and continuing between years. To examine this question, we grouped results in three-year periods and examined productivity change for entering, exiting and continuing vessels in each time period. We chose three-year time intervals because after the transition to ITQs there were years when zero vessels entered or exited in a given year. Our results prior to implementing the ITQ show a period of entry by vessels leading up to implementation of the ITQ (table 4), followed by a large number of vessel exits during the period after transition to the ITQ regime. There was little entry of new vessels after transition to ITQs. We find that entering and continuing vessels showed positive productivity gains in the period leading up to implementation of the ITQ management regime (1981–1989), while exiting vessels showed productivity gains from 1981–1986 (table 5). Vessels which exited immediately after implementing ITQs showed declining productivity. This trend of declining productivity for exiting vessels continued until the 2002–2004 time period, when productivity increased slightly. In the early years after transition to ITQs (1990–1995), continuing vessels showed increasing productivity, and then declining, or no productivity gains after 1996. Entering vessels showed increasing productivity immediately after implementing the ITQ regime, before showing no gain over the next two periods. Then, over the next decade (1999–2008), entering vessels showed increasing productivity. Since the ITQ itself creates an additional barrier to entry, vessels without an initial quota allocation must purchase or lease quota, suggesting that these vessels will likely need to be more productive to overcome the cost of quota purchase or lease. However, we also observe that the productivity of continuing vessels did not increase at the same time. Often when firms in traditional industries see a threat of entry, they will increase their productivity in response to the threat (Holmes and Schmitz 2010). This does not seem to occur for our group of continuing fishing vessels.

Table 4. Number of Continuing, Entering, and Exiting Vessels, 1981–2008

Time Period	Vessels	Continue Next Period	Enter Current Period	Exit Next Period
1981–1983	100	95		5
1984–1986	121	111	26	10
1987–1989	134	117	23	17
1990–1992	124	61	3	63
1993–1995	64	52	3	12
1996–1998	53	40	1	13
1999–2001	43	43	3	0
2002–2004	56	43	13	13
2005–2008	47	43	4	

Discussion

The decline in vessel productivity over the past dozen years was a surprising result of this study, and we found no single explanatory factor for this decline. We believe that worsening resource conditions resulting from fishing down productive fishing beds along with external factors outside the control of fishing vessels have both contributed to our findings. The resource condition and the declining biological productivity of heavily fished beds have also raised concerns among stock assessment scientists (L. Jocobson, Northeast Fisheries Science Center personal communication), and fishery managers. A recent quota specification paper has described the clam industry as an “industry under stress,” (MAFMC 2010). Because aggregate biomass estimates were used in our analysis, we acknowledge that estimating productivity using a finer spatial scale may have yielded different results. As we will discuss below, fishing location and the condition of the underlying beds seem to matter. Unfortunately, disaggregated biomass data and fine scale fishing location data were unavailable for the entire time period.

Table 5. Mean (geometric) Productivity of Continuing, Entering, and Exiting Vessels in the Surfclam and Ocean Quahog Fleet, 1981–2008

Time period	Current Period Productivity Continuing Vessels	Current Period Productivity Entering Vessels	Current Period Productivity Exiting Vessels
1981–1983	1.14		1.05
1984–1986	1.09	1.3	1.14
1987–1989	1	1.11	0.93
1990–1992	1.09	1.06	0.97
1993–1995	1.01	1	0.88
1996–1998	0.99	0.95	0.85
1999–2001	1	1.27	N.A.
2002–2004	0.97	1.12	1.02
2005–2008	0.96	1.07	

From 1982–2008, both the surfclam and ocean quahog biomass shifted northward, accompanied by a decline in southern areas, and forecasts indicate that this will continue through 2015 (MAFMC 2010). For surfclams, the portion of the total resource in the Georges Bank restricted area was about 48% in 2008 versus 5% in 1986. Similarly, the portion of the total ocean quahog resource in the Georges Bank restricted area was estimated to be 45% in 2008 versus 33% in 1978. The increased proportion of both stocks on Georges Bank is due to fishing down the resource in the Mid-Atlantic area, and not by movement of the animals (MAFMC 2010). Managers have characterized the overall state of the surclam resource as similar to the condition which existed in the early 1980s before ITQs were in place (T. Hoff, MAFMC personal communication).

In terms of surfclam production, vessels depend most heavily on one single degree square block outside the Georges Bank region located off the coast of New Jersey. As vessels have concentrated on these beds, their biomass has declined, the resource has become less dense, and vessels have spent more time fishing and searching for additional clams; vessels have not found large dense beds of surfclams to replace these ones. Biologists examining trends in surfclam landings per hour of fishing time (LPUE) found that between 2000 and 2009, LPUE declined by an average of almost 10% per year, from 129 bushels per hour to 52 bushels per hour (MAFMC 2010). The impact on vessels from the decline in abundance has resulted in substantially increased fishing time at sea over the past decade (figure 3).

The resource condition for the ocean quahog stock resource has also deteriorated in the available fishing areas since ITQ implementation. Currently, the ocean quahog beds with the highest catch rates are found substantially offshore, meaning vessels spend more time at sea. In 2008, the average hours reported fishing on each trip increased 10% over 2007 levels (MAFMC 2010). Additionally, the depth of the ocean quahog beds being fished can be up to 300 feet, which is pressing the limit of modern technology. Finally, the ocean quahog resource is much less productive biologically than the surfclam stock. Coupled with their distance from shore, and the depths from which they are harvested, this means that harvesting costs are higher for quahogs than surfclams, and is one possible reason for the shifting production from ocean quahogs to surfclams that has occurred.

The shift in biomass to the north has also been accompanied by the closing of processing capacity in the mid-Atlantic region. A large processor, Eastern Shore Seafood Products of Mappsville, Virginia, began scaling back operations in 2005, and shut down completely in 2008. Processing operations were moved to plants owned by another large processor in Maryland and Delaware. Because vessels need to offload at processing facilities which have equipment that can lift heavy metal cages, this forced vessels which offloaded at Eastern Shore Seafood to travel further to offload their clams. At the same time processing capacity has decreased, there has been an influx of harvesting capacity. It was noted in the last quota specification document that large, newly constructed vessels entered the ocean quahog fishery in 2001 (MAFMC 2010). This can be seen in the capital index (figure 3) mentioned previously, where the index starts to increase after 2001. Using more capital input with flat or declining outputs will lead to declines in productivity. This effect may be further amplified if the vessels are spending more time at sea searching for clams, or harvesting beds where their abundance is declining. Search behavior can be thought of as "learning-by-doing" (Marcoul and Weninger 2008). If vessels are returning to previous locations because of unsuccessful searches elsewhere, they can accelerate the depletion of known clam beds since the animals are sessile. This leads to vessels spending more time at sea to harvest their quota since the density of the beds has declined.

A final point to consider is that an ITQ is simply a mechanism for distributing fishing quota, which is determined through a fishery management plan quota-setting process. Instituting an ITQ does not guarantee improvements in productivity because other parts of the management plan may restrict productivity gains. In this fishery, quotas are based on the entire range of the resource, including biomass in the Georges Bank restricted area. This may have allowed the stocks in the Mid-Atlantic region to be overfished because a quota based solely on that region would likely be far lower. Since vessels cannot reach higher-yielding fishing locations on Georges Bank, and stock biomass declined in open areas, vessels were unable to sustain early productivity gains. This could change if at-sea protocols under development to test for PSP allow vessels to fish on Georges Bank.

Summary and Conclusions

Our study measured fishing vessel productivity change before and after the 1990 implementation of a market based mechanism (ITQs) to manage the Mid-Atlantic surfclam and ocean quahog fishery off the east coast of the United States. Because the fleet was previously regulated and managed through a "command and control" system of limits on fishing time and capital replacement, we expected productivity to improve post-ITQ. Indeed, our findings confirmed earlier studies, which showed productivity gains for the fleet immediately following implementation of the ITQ program. However, these productivity gains were not sustained, and productivity has since declined. Additionally, technical and scale efficiency both declined since enactment of the ITQs in 1990. However, the technical change component of the MI increased and then stabilized at a high level.

Decomposition of the technical change component into three elements revealed that technical change is not Hicks-neutral, and a large increase occurred in output biased technical change, while input biased technical change declined. External factors such as differences in dockside prices for the two mollusk species, and final demand for the products produced from these species may have influenced the output biased technical change shift. Differences in the inshore-offshore distribution of the two species, as well as their stock biomass levels, may also have contributed to the change. Input biased technical change is likely being driven by increasing effort levels relative to the capital stock once ITQ management started. During the early years of the program, capital exited the fishery and the remaining vessels increased effort levels to increase their harvest.

Results showed that vessels which entered after implementing ITQs generally were more productive than continuing vessels, and vessels which exited the industry were less productive. This is what one might expect after the transition to an ITQ system. Unlike other industries, survivor firms did not increase their productivity post-ITQ. Since an ITQ creates an additional barrier to entry, and the ITQ is usually given away freely, vessel owners may not be concerned about increasing productivity to deter entry by new competitors. The dynamics of firm reaction to entry may be different in an ITQ fishery than in other fisheries, or other industries. A complicating factor in fully understanding how this particular industry has changed post-ITQ is a lack of data on input prices and output price data, which may not truly represent market prices. This leaves us unable to determine if post-ITQ firms were able to increase profitability through cost savings or price increases, rather than productivity gains.

The implementation of a market-based management system for surfclams and ocean quahogs undoubtedly lowered management costs and facilitated the exit of a large amount of vessel capital. However, claims of increased efficiency at the vessel level arising from the ITQ management system are simply untrue. Furthermore, the productivity gains observed in the first years after implementation have not been sustained. Because an ITQ is not a complete property right, externalities still exist, which may limit a vessel's ability to increase productivity. For example, a vessel could choose to fish heavily on clam beds close to shore to harvest its quota. This could force other vessels to shift their fishing efforts further offshore, thereby increasing their input usage and lowering their productivity. The management plan which governs the ITQ is also important. Closure of a large fishing area, combined with declining productivity of clam beds in open areas may have contributed to declining vessel productivity in this fishery. Regulators should consider that imposing additional regulations, such as area closures, on top of an ITQ program, may have unintended consequences on vessel performance and ultimately on profitability.

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