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Abstract

A principal challenge in developing any fishery management plan is the allocation of benefits and costs among participants in the fishery. This process is further complicated by imperfect information about future market demand and limited ability to predict the consequences of regulatory change. This paper offers a new approach to policymakers, using econometric analysis to simulate the potential impact of individual tradable quotas (ITQs) in a fishery. We compare the distribution of harvest across participants in the Atlantic Herring fishery under the current open access regime and under a potential ITQ regime, assuming two different levels of future demand. Our results show that production efficiency varies by vessel gear, home-port and relationship with buyers. Some of the predicted consequences of ITQs are: vessels from Massachusetts will gain share relative to those from Maine; trawlers will gain share relative to purse seine vessels; and independent vessels will lose share relative to vessels that are primarily contracted to specific processors or bait companies. These results will help policymakers in developing future management plans for the herring fishery. More generally, this analytical approach can help regulators in any fishery assess the potential impact of alternative policy changes under alternative future demand scenarios.

Keywords: Property rights; Equity; Distributional effects

1. Introduction

Effective fisheries management requires a skillful balance between addressing immediate crises and creating protective policies using imperfect information about future conditions. In practice, management efforts in the United States have typically been reactive because of the difficulty of designing policies flexible enough to respond to unforeseen changes in fisheries. Economists often propose tradable property rights as a cost-effective management option that has minimal information requirements. But despite their theoretical advantages, regulators are often concerned with the distribution of benefits and costs from implementation. We address this question by using an economic model of equilibrium under tradable property rights to simulate the distributional effects of implementing tradable property rights in the Atlantic herring fishery under current and potential future market demand.

Discussions of major changes in regulatory approaches, such as creating tradable property rights, generally occur in fisheries in obvious need of change. In contrast, conditions in the Atlantic herring fishery seem refreshingly benign. By most standards the fishery has remained consistently underexploited since the implementation of its fisheries management plan (FMP) in 2000. Annual harvests over the past four years have not exceeded aggregate quotas, while a number of stock assessments have jointly concluded that the herring biomass has remained stable, if not growing, over time.[1] Compared to the need to address current

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[1]While in general scientific assessments indicate that herring biomass as a whole has been increasing over time, estimates of the amount vary. For a complete assessment, see Summary of Stock Status in the Proposed Atlantic Herring Specifications Document (http://www.nefmc.org/herring/index.html) for the 2005 fishing year.

unsustainable practices in other fisheries, expending management resources in the Atlantic herring industry may appear inefficient.

From the fishery stakeholders' perspective, however, this is the appropriate time to take action because of demonstrable excess capacity in the fleet. Proactive fisheries management is a potential way to avoid the more drastic measures typically used to remedy problems resulting from short-sighted regulatory policies. Neighboring fisheries like the spiny dogfish and the Atlantic wreckfish fisheries, considered underexploited less than two decades ago, have been deemed overfished by the regional management councils and have subsequently witnessed a variety of emergency closures and restrictions [1,2]. Furthermore, the current herring stock levels follow a history of large declines in stocks and fishery closures. The interest in preemptive action may also reflect the recognition that any policy change produces a re-distribution of benefits and costs: as a result, proactive participation in redesigning management plans is economically rational.

The Atlantic herring management council has proposed a number of forward-looking management options designed to ensure a sustainable commercial fishery: the most contested proposals are a variety of limited entry and tradable fishing permit schemes [3]. This paper contributes to the ongoing discussion of proactive management in the Atlantic herring fishery by: (1) estimating the level of overcapitalization and potential harvest capacity of the existing boats; and (2) characterizing the long-run distributional impact of implementing an individual tradable quota (ITQ) system. First, we estimate a stochastic production function to arrive at technical efficiency values for each vessel in the fishery. The fitted model allows us to predict the level of harvest by increasing effort levels. We are then able to estimate the most efficient fleet structure needed to capture any given total allowable catch (TAC). Second, we characterize the long-run surviving fishing fleet (by gear type, contract type, home port state and gross registered tonnage [GRT]) under a functioning ITQ system. We focus on these characteristics because they are the features that delineate stakeholders in the debates about the distributional impact of policy change.

The paper is organized as follows: Section 2 provides a brief description of how the fishery is presently regulated and the direction of future regulation. Section 3 presents the model and methodology. The following two sections describe the data set, its sources, and summary statistics, and then the regression results and technical efficiency estimates. Section 6 describes the simulation and the final section provides concluding remarks.

2. Atlantic Herring fishery

2.1. Motivation for regulatory change

The current herring Federal Management Plan (FMP) consists of caps on annual harvest levels (disaggregated by management areas) and specific gear restrictions (Herring FMP 2000). As a result, access to the fishery remains open, making it susceptible to a flooding of new entrants and a potential "derby style" race to the total allowable catch (TAC). Economic models show that in fisheries with harvest restrictions and without restrictions on entry, an unbounded number of boats chase a fixed number of fish, promoting inefficiencies and overcapitalization in the fishery [5,6]. Empirical evidence from existing ITQ programs suggests that property rights systems can reduce the level of excess capital employed in the fishery [7–9]. For a review of the empirical literature, see [10].

Aggregate harvests under the FMP have averaged roughly 100,000 metric tons (mt) annually, falling about 80,000 mt below the fishery-wide TAC. Currently, the binding constraint on harvests is market demand, but there are both anecdotal and price data to suggest that these conditions will change in the near future. Since the mid-1980s, herring has been predominately sold as lobster bait to fuel the thriving, and very lucrative, American lobster fishery [4]. The lobster fishery is the most valuable commercial fishery on the Atlantic coast of the US and Canada, with dockside values of American lobster sales surpassing 300 million dollars at the beginning of the 21st century. Annual lobster landings between 1980 and 2003 grew at an average annual rate of 3.3% while the annual value of the total catch (reported landing price) increased an average of 6.5% annually [11]. Meanwhile, new developments in information and shipping technologies have enabled the lobster industry to meet demand beyond the New England area. The creation of the "Habitat Packing Solution," designed to ship live lobsters to virtually any destination in the world, has allowed many Maine-based companies to meet West Coast and international demand for fresh lobster [12]. Many fishermen and industry representatives have voiced their concern that they foresee an increase in overall effort sparked by a positive shock in market demand.

> "This is a concern that I have—that the licenses on this coast could catch the quotas. The only regulating factor right now is market [...]. It's been the markets that have regulated our participation, but change [in market demand] is in the wind." Dan Axelsson [13].

Even in the absence of new entrants, the existing herring fishing fleet has the capacity to significantly surpass TAC [14].[2] The inefficiencies that would be created by the introduction of currently unutilized capital are a primary

[2]The Herring Plan Development Team (PDT) included estimates of harvesting capacity for the existing fishing fleet using data envelopment analysis (DEA). Although our analysis also estimates potential harvesting capabilities, we use a parametric approach. Most importantly, this allows us to calculate efficiency scores for each vessel to characterize the fleet under ITQ management. In addition, the frontier approach allows us to test our expectations.

concern among herring fishermen and management, and the issue is repeatedly raised in policy planning.[3]

2.2. Debates over distribution of benefits and costs

Recognizing the immediate and potential problems with the current management plan, the New England Fishery Management Council and the Atlantic States Marine Fisheries Commission are working together on the first amendment to the 2000 FMP. As a starting point, a number of new objectives have been developed for the plan, including "Prevent excess capacity in the harvesting sector" and "Minimize, to the extent practicable, the race to fish for Atlantic herring in all management areas" [3]. The primary measures proposed in the amendment to address these problems are: (1) various limited access/entry schemes, and (2) establishing purse seine/fixed gear only fishing areas.[4]

Much of the conflict as to what management measures are appropriate is due to distributional issues. We identify three characteristics that distinguish participants in the fishery: port state, vessel type, and contract type. In each case, different types of participants have different objectives and therefore different policy preferences.

Massachusetts and Maine are the primary ports for the herring fishery, and their relative performance under policy alternatives will likely drive their positions during policy negotiations.

Fishermen and management have voiced concern about exacerbating conflicts between vessels in a derby-style race to fish in the prime inshore harvesting location (management area 1A).[5] The increasing crowding in the area has pitted seine vessels, who endorse gear-specific fishing areas, against trawl vessels. Proponents of gear-specific fishing areas argue that the growing trawl fleet is able to travel further distances to fish compared to the purse seine vessels, which are limited to the inshore areas; without seine-dedicated areas, they argue, the fleet will be increasingly dominated by trawlers. In addition to gear type, vessels' comparative advantages can be distinguished by their gross registered tonnage. These conflicts between gear classes over unequal distribution of policy benefits and costs are evident in other fisheries and have been shown to affect policy decisions [15–17].

Relationships between fishermen and their buyers are very important in this fishery, in which vessels leave port only when they have a confirmed buyer. In recent years approximately 60% of herring landings have been sold as lobster bait, with the reminder sold to processors for the frozen or canned fish markets. Long-run fishery participants, who have sold primarily to bait-buyers, argue that historic participation should be a primary factor for eligibility under limited entry or individual tradable quotas. Meanwhile, processors with vessels that became active after the 2000 management plan are actively lobbying to secure permits for their fleets, irrespective of tenure in the fleet. The fundamental dispute is over how to distribute the valuable harvesting quota and/or permits.

> "…I am seeing boats coming over from the West Coast, and others wanting to get into it, and all of these freezers that are trying to build up to freeze bait and sell it at a higher price. I can see what they are doing. We are going to have to do something about limited entry, and it's going to have to happen soon." Dan Fill, a purse seine captain [13].

3. Model and methodology

To derive vessel-level measures of technical efficiency, we use federal logbook data on individual landings, input choices and vessel characteristics to estimate a stochastic production frontier. Harvest of herring is assumed to be stochastic because of the nondeterministic effects of weather, resource stock and environment. For each vessel, the level of inefficiency is calculated as the mean distance a fisherman's production is from the best-practice frontier [9,18]. This approach operates under the assumption that the conventional error term ε can be expressed as $\varepsilon = v - u$, where v is a purely stochastic term that captures exogenous shocks while u is the measure of technical inefficiency. The two-sided error term v is assumed to behave as under the classical regression assumptions, being distributed normally with mean zero and a constant variance. The exact distribution given to the inefficiency component is decided by the econometrician and usually takes the form of a half-normal, an exponential, or a truncation of the normal distribution at 0. The inefficiency term is constrained to be non-negative to ensure no firm can perform better than the best-practice frontier [19].

Following similar studies in the literature,[6] we specified the translog functional form shown in Eq. (1) for the Atlantic herring fishery. The function translates herring harvest by individual vessels as a function of variable and fixed input choices according to specific gear type. We use the translog function because it imposes the fewest restrictions on input substitution of all available functional

[3]See revised goals in Amendment 1 (draft) to the Herring Fishery Management Plan 2005.

[4]The fishery is divided into four management areas; 1A, 1B, 2, 3, and the bulk of fishing effort is concentrated in area 1A. The proposed gear specific fishing area would preserve a portion of the area 1A quota for seine vessels and is based on the argument that the growing trawl fleet are able to travel further distances to fish compared to the purse seine vessels that are restricted to the inshore areas.

[5]The "days out" regulation, restricting fishing to a five-day week, included in the ISHMP was first initiated by fishermen (Personal communication, Mary Beth Tooley 2004). The ASFMC supported the restriction and recommended to the council to include it in the FMP. The provision is now included in Amendment 1 to the FMP.

[6]We followed closely the specification by Squires, Grafton, Alam and Omar (2003).

forms, and we characterize the inefficiency term with a half-normal distribution as is typical in the literature[7] [20].

$$
\begin{aligned}
\ln harvest_{it} &= \alpha_0 + \alpha_1 \ln days_{it} + \alpha_2 \ln grt_i + \alpha_3 \ln crew_{it} \\
&\quad + \alpha_4 \ln age_{it} + \alpha_5 \ln days_{it}^2 + \alpha_6 \ln grt_i^2 \\
&\quad + \alpha_7 \ln crew_{it}^2 + \alpha_8 \ln age_{it}^2 \\
&\quad + \alpha_9 \ln days_{it} \ln grt_i + \alpha_{10} \ln days_{it} \ln crew_{it} \\
&\quad + \alpha_{11} \ln days_{it} \ln age_{it} + \alpha_{12} \ln grt_i \ln crew_{it} \\
&\quad + \alpha_{13} \ln grt_i \ln age_{it} + \alpha_{14} \ln crew_{it} \ln age_{it} \\
&\quad + \alpha_{15} seine + \alpha_{16} weir + \alpha_{17} year2001 \\
&\quad + \alpha_{18} year2002 + \alpha_{19} year2003 \\
&\quad + v_{it} - u_{it}. \qquad (1)
\end{aligned}
$$

Harvest is annual herring harvest for each vessel i in year t; *days* is the sum of vessel i's fishing days in year t and acts as our measure for variable effort; *age* is the age of the vessel in years, which reflects embedded technology; *grt* is the gross registered tonnage, used as our measure of capital stock; *crew* is the average crew size for vessel i in year t, used as a measurement for labor input. We expect the signs on days fishing, gross registered tonnage, and crew size to have positive effects on harvest, while an increase in the age of a vessel should have a negative effect. As for the squared terms, theory suggests we should see a diminishing marginal productivity of labor, effort and capital. The differences in gear types are reflected in the two dummy variables *seine* and *weir* used to measure shifts in the intercept relative to trawl vessels. The three-*year* dummy variables are included to capture any time effects relative to year 2000. These variables may account for a number of changing conditions, including the size of the resource stock. A detailed description of the data and its sources is provided in the next section.

Before calculating vessel-level efficiency terms, a number of hypotheses concerning the model can be tested. First, we can test if technical inefficiency exists in the fishery by setting up the null hypothesis Ho: $\gamma = 0$, where $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$ which falls between zero and one. If we fail to reject the null, we should remove the inefficiency component and revert to estimation using ordinary least squares. Second, to determine if the translog is appropriate as opposed to the Cobb–Douglas formation, we set up the following null and alternative hypotheses: H_0: $\alpha_5 = \alpha_6 = \cdots = \alpha_{14} = 0$, H_a: at least one coefficient is different from zero. The results of these tests are provided in Section 4.

Individual vessel's efficiency scores can be derived, as in Eq. (2) below, by taking the ratio of observed output conditional on the estimated inefficiency term u to the estimate of the best-practice frontier (maximum output with $u = 0$).

$$TE_{it} = \frac{E(harvest_{it}|u_{it})}{E(harvest_{it}|u_{it} = 0)}. \qquad (2)$$

[7]The half normal distribution is the absolute value of a normally distributed variable.

4. Data

The data are the individual trip reports by fishermen for each fishing day throughout the year, collected by the National Marine Fisheries Services (NMFS) federal logbook data set for years 2000–2003. (Logbook data were not available before 2000 because the Atlantic herring fishery was not under the jurisdiction of a federal management plan.) The data include harvest amount, trip length, crew size, management area and gear used. The set also contains a number of vessel characteristics including gross registered tonnage, vessel length, engine horsepower, owner information, and capacity measures.[8] We chose to annualize the trip data in order to dampen the effects of large, short-term fluctuations in harvest, thus allowing for a "smoother" production function. Missing (or questionable) entries were verified and completed, when available, using the US National Coast Guard Database. Due to the nature of the reporting process, a number of other data-cleaning steps needed to be taken before we could proceed with estimation. These steps are described in an appendix available from the authors.

We limited our analysis only to those vessels with gear used to target herring. Based on conversations with representatives from the Maine Department of Marine Resources and the NMFS, we included purse seine, pair trawl, single trawl, and weir vessels, which together account for roughly 99% of the total harvest. For the stochastic production estimation we included dummy variables for purse seine and weir vessels. These coefficients therefore can be interpreted as variations in the intercept compared to the trawl vessels. We decided to combine the pair trawl and single trawl into a single gear category because they only vary in scale, not technology. The fishing practices of weirs and purse seines are, however, very different from those of the trawlers.[9]

Vessel ownership within the fishery is important because it defines what industry groups will potentially gain (or lose) from policy change. While very few boats in the herring fishery are legally owned by processors or bait dealers, there are a number of vessels that are effectively dedicated to these companies through formal contracts or informal relationships. The vessels included in our analysis were divided into one of three contract classes: processor contracted, bait-company contracted, or independent [21].

[8]We chose vessel weight over vessel length as the measure of capital stock. Horsepower was highly correlated with both measures so it was excluded from the analysis. Capacity measures were missing for roughly half the logbook entries and were therefore not included.

[9]For a complete description of the three gear types, see http://www.gma.org/herring.

Processor-contracted vessels exclusively supply herring to one of the three large processing companies or to the single remaining sardine cannery. The bait-company-contracted boats sell their entire catch to a single or very limited set of bait dealers. The remaining vessels, the independent boats, are not restricted to selling their catch to single processing firms or bait dealers. Many of these independent vessels sell to multiple processors and multiple bait dealers within a given year. While the dominant contract type is independent, multiple large trawl vessels that have recently entered the fishery are distinguished by their exclusive contracts with large processors. The recent emergence of these processor-contracted vessels may be an attempt to capture a portion of the TAC given the prospect of an ITQ-managed fishery. We determined the contract type of each boat by conducting industry interviews and examining the logbook data.

Finally, it was important to determine which state had the largest stake in the performance of each vessel [10]. In all but a few cases, boats were reported to hail from the same state in which the vessel owner lived and therefore we used that state as the HPS (home port state). For those boats with vessel owners living in a state different from the reported hailing state, we used the state in which the vessel reported the majority of its landings. The Massachusetts and Maine fisheries are of primary interest in our study because these two states produce the majority of the annual harvest and supply the lucrative lobster fishery with herring as bait.

Summary statistics are shown in the tables below. There is large variation in vessel weight and horsepower within the fleet. Trawlers, on average, are twice as heavy and have three times the horsepower of purse seine boats. The weir boats are significantly smaller and less powerful than the other gear types. Weirs also fished very few days and averaged only .58 mt/day (Table 1).

The Atlantic herring fishery has witnessed several significant changes in dominant gear type in the past few decades. In the beginning of the 1980s, fixed-gear vessels (weirs and stop seines) accounted for roughly two-thirds of the total harvest. However, since 1984 these gear types have only contributed an average of around 1000 mt annually

Table 1
Summary statistics of the data 2000–2003

Vessel and fishing characteristics	Mean	Median	St. Dev	Min	Max
All gear types					
Gross registered tons	142.80	165	101.26	5	476
Engine horsepower	962.76	850	619.94	150	2985
No. of fishing days per year	96.18	66.50	90.57	1	341
Avg. crew size (including captain)	4.19	4	1.79	1	12.33
Annual harvest (metric tons)	3161.67	1489.71	3889.93	.01	19184.97
Catch per day (metric tons)	22.95	24.39	15.98	.01	72.12
Vessel age	21.07	20	8.31	5	55
Trawl					
Gross registered tons	163.67	174	99.09	5	476
Engine horsepower	1117.98	1125	614.52	160	2985
No. of fishing days per year	94.85	58	94.95	1	341
Avg. crew size (including captain)	4.02	4	1.89	1	12.33
Annual harvest (metric tons)	3175.42	1201.82	4145.04	.01	19184.97
Catch per day (metric tons)	23.46	24.22	16.22	.01	72.12
Vessel age	20.40	20	7.07	5	45
Purse seine					
Gross registered tons	80.58	66	71.63	5	192
Engine horsepower	452.17	480	112.83	150	580
No. of fishing days per year	121.38	138.50	64.52	2	225
Avg. crew size (including captain)	5.08	5.39	.93	3	6
Annual harvest (metric tons)	3760.86	4281.28	2728.23	.59	8651.32
Catch per day (metric tons)	25.42	27.92	13.08	.29	43.92
Vessel age	23.71	20.50	12.63	6	55
Weir					
Gross registered tons	11.60	12	.55	11	12
Engine horsepower	216	250	46.56	165	250
No. of fishing days per year	2.60	2	2.07	1	6
Avg. crew size (including captain)	3.47	4	1.76	1	5
Annual harvest (metric tons)	2.25	.68	3.27	.09	7.94
Catch per day (metric tons)	.58	.45	.47	.09	1.32
vessel age	22.20	25	3.83	18	25

Source: NMFS logbook data.

Table 2
Percentage of harvest by gear, HPS, contract type and GRT 2000–2003

	Percentage of harvest
Gear type	
Purse seine	22%
Single trawl	25%
Pair trawl	53%
Weir	.001%
Home port state	
MA	33%
ME	44%
NH	6%
NJ	8%
RI	9%
Contract type	
Processor contracted	10%
Bait company contracted	14%
Independent	76%
GRT	
Low (Q1)	3.00%
Medium (Q2 &Q3)	56.6%
High (Q4)	40.4%

Source: NMFS logbook data.
Note: "Low", "Medium" and "High" gross-registered tonnage refers to the first quartile, the middle quartiles and the fourth quartile, respectively, for vessels in the data set.

[22]. The purse seine fishery dominated between 1984 and 1997, averaging 76% of total harvest and peaking at 92% of the total in 1991 [11]. Beginning in the mid-1990s, a series of trawl vessels has entered the fishery, and trawlers have captured the largest percentage of the catch. Table 2 shows the current distribution of harvest by each of these vessel groups.

5. Estimation results

5.1. Parameter estimates and hypothesis tests

The regression results for the stochastic production model are shown in Table 3. Because we are primarily interested not on individual parameter estimates but on the predictive power of the model, we will only briefly discuss the signs and significance of the coefficients.

The positive signs attached to days fishing, gross-registered tonnage, and crew coincide with our theoretical predictions, although only the former two are significant at the 10% level. An increase in vessel age negatively effects harvest, but the impact is not significant. The results indicate a significant diminishing marginal productivity of labor at the 1% level (crew-squared variable). The effect on harvest from an increase in boat size and days fishing is

Table 3
Parameter estimates of the stochastic production frontier

Variables	Coefficient	Standard error	Test statistic	*p* value
lndays	0.935976	0.494452	1.89*	0.058
lngrt	1.798043	1.019739	1.76*	0.078
lncrew	2.945938	2.122594	1.39	0.165
lnage	−0.81987	1.573313	−0.52	0.602
lncrewsq	−1.30736	0.296509	−4.41**	0.000
lnagesq	0.014716	0.342605	0.04	0.966
lngrtsq	−0.04836	0.090812	−0.53	0.594
lndayssq	−0.02141	0.033755	−0.63	0.526
lngrtlncrew	0.244301	0.289462	0.84	0.399
lngrtlnage	−0.16699	0.182243	−0.92	0.359
lndayslngrt	−0.19798	0.055879	−3.54**	0.000
lndayslnage	0.35691	0.154581	2.31**	0.021
lndayslncrew	0.203763	0.175523	1.16	0.246
lnagelncrew	−0.35441	0.753596	−0.47	0.638
Weir	0.535526	0.39765	1.35	0.178
Seine	0.379148	0.249499	1.52	0.129
yr2001	−0.3106	0.171098	−1.82*	0.069
yr2002	−0.52262	0.157853	−3.31**	0.001
yr2003	−0.28267	0.178977	−1.58	0.114
constant	−1.432	3.125376	−0.46	0.647
/lnsig2v	−2.98617	0.964657	−3.1	0.002
/lnsig2u	0.27283	0.235846	1.16	0.247
sigma_v	0.224678	0.108369	—	—
sigma_u	1.146157	0.135158	—	—
sigma2	1.364157	0.274041	—	—
Lambda	5.10133	0.229341	—	—

Likelihood-ratio test of sigma_$u = 0$: chibar2(01) $= 22.53$ Prob$>=$chibar2 $= 0.000$.
*Statistically significant at the 10% level.
**Statistically significant at the 5% level.

significantly negative at the 1% level. The only other significant interaction variable is a negative relationship between harvest and an increase in vessel age and days fishing. Gear type does not prove to have a significant effect. The dummy variables for fishing years, which capture any differences in harvest that are not captured by the inputs to production, each indicate a decrease in the intercept compared to the year 2000. Why this relationship is consistently negative, and strongly significant in 2002, remains unclear. It is difficult to determine the statistical significance of individual coefficients due to collinearity of inputs, but the model as a whole has significant explanatory power and is sufficient for the question at hand.

The first test, of whether the translog is the appropriate functional form, yields an F statistic of 103.90 with a corresponding p-value $< .000$. Therefore, we reject the null hypothesis that the coefficients on the squared terms and cross products are all zero and conclude that the flexible functional form is a better fit than the Cobb–Douglas.

The second test to determine if technical inefficiencies exist in the fishery produces a $\gamma = .96$ with a corresponding test statistic of 22.53 distributed as a mixed χ^2 [10] (p value $< .001$). Thus we reject the null hypothesis that all variation from the fitted regression is due to random white noise and proceed using the stochastic production estimation results. This test provides evidence that vessels do vary in their level of technical efficiency.

Table 4
Distribution of efficiency scores by gear, HPS and contract type

	Mean efficiency	High	Medium	Low	Total
Gear type					
Purse seine	.569	2	5	2	9
Trawl	.512	11	22	10	43
Weir	.428	0	1	1	2
Total	—	13	28	13	54
Home port state					
MA	.583	5	5	3	13
ME	.474	7	11	9	27
NH	.615	1	3	0	4
NJ	.555	0	4	0	4
RI	.492	0	5	1	6
Total	—	13	28	13	54
Contract type					
Processor contracted	.499	0	5	2	7
Bait company contracted	.616	2	3	0	5
Independent	.510	11	20	11	42
Total	—	13	28	13	54
GRT					
High (Q4)	.571	3	9	1	13
Medium (Q2 & Q3)	.526	7	15	6	28
Low (Q1)	.451	3	4	6	13
Total	—	13	28	13	54

Note: "Low", "Medium" and "High" gross registered tonnage refers to the first quartile, the middle quartiles and the fourth quartile, respectively, for vessels in the data set.

5.2. Technical efficiency scores

Vessel-level technical efficiency scores for each fishing year were obtained using Eq. (2). The distribution of efficiency scores by gear, home port, contract type and GRT are shown in Table 4. The first column, "mean efficiency," is the average for that category of vessels. The columns "low", "medium", and "high" show the number of vessels in each of the three efficiency classes, where "high" and "low" consist of the fourth and first quartiles of efficiency scores, respectively, while "medium" consists of the second and third quartiles. Vessels were similarly separated into quartiles depending on their gross-registered tonnage.

On average, purse seine vessels had slightly higher technical efficiency scores over trawlers, while weirs proved to be the least efficient gear type. Vessels from New Hampshire had the highest average efficiency score, which can be explained in part because the state harbors such few vessels, one of which is a highly efficient bait-company-contracted boat. Efficiency is increasing in vessel size; this may generate policy concern over the equity of tradable quota programs since the least-efficient, smaller boats may be forced out of the fishery. In addition, the more recent processor-contracted vessels are among the least efficient, a result similar to that found in other studies [16,17].

5.3. Predictive power of the model

Stochastic production estimation allows us to use the additional information contained in the two-part error term for more realistic simulations of various policy alternatives. In the next section we first use our fitted model to predict the impact on overall harvest of a demand-induced increase in effort. Then we use the technical efficiency scores to characterize the fleet structure in the long and short run under an individual tradable quota scheme.

In order to proceed with the simulations, we must first attribute a single inefficiency estimate (u_{it}) to each vessel (recall that vessels may have between 1 and 4 estimates depending on how many years they were active in the fishery). To determine which summary measure is most appropriate to include in the parameterized model, we use data from 2000–2002 to predict total harvest for 2003. The predicted harvests for 2003 using the minimum, mean and maximum inefficiency estimates from the previous three years were 89,438, 76,468, and 67,574 mt, respectively, while the actual 2003 harvest was 83,124 mt. To avoid overstating potential harvesting capabilities, we will use the mean inefficiency estimate in the simulations that follow.

[10] The null hypothesis states that γ equals zero, which would be on the boundary of the parameter space. Therefore, the distribution of the test statistic for gamma is a mixed χ^2.

The next section uses the fitted regression model and technical efficiency measures to guide proactive herring management in two ways; first we estimate the extent of existing capacity in the fishery, and second we predict the distributional impact on the harvest of a tradable property rights system.

6. Simulations

6.1. *Increased effort of current fleet*

In this section we demonstrate that pre-emptive regulation is rational, given the potential for a "race for fish". Changes in demand for herring are tied to changes in the downstream lobster bait, frozen fillet, and canned fish markets; we proceed under the reasonable assumption that increased demand will cause an increase in overall fishing effort. In this section we use conservative estimates of vessels' maximum effort levels to predict the resulting aggregate harvest.

By varying each vessel's number of days fishing in our model, we can predict the impact of an increase (or decrease) in fishing effort. In this particular fishery, it is entirely reasonable to assume that many boats are not fishing at full capacity.[11] However, it is not likely that all boats have the same technical constraint on the maximum level of effort (days at sea) they can fish. We divided the 54 boats into four size classes depending on their gross registered tonnage. Following the advice of industry experts,[12] we assumed the boats in the smallest size class were already fishing at maximum capacity due to technical constraints. The remaining vessels were assumed to fish the number of days equal to the most active fisher in their size class. Therefore, our estimate of maximum harvest potential is conservative because it does not allow the smallest quintile of boats to increase their effort levels, nor does it allow current vessels to expand their capacity.

The predicted harvest from maximum effort given these assumptions (Table 5) can be compared to the TAC for the 2005 fishing year (Table 6) for a measure of excess capacity beyond what is allowed by the annual quota.

Although we cannot determine the exact allocation of harvest between each area, it is obvious that the existing fleet has the potential to far exceed the 180,000 mt TAC by simply matching the effort level of the most active fisher in each vessel's respective size class. The guiding policy implication is that even in the absence of new entrants, there is a significant level of overcapitalization, and therefore inefficiency, in the fishery.

We can say a little more about how the increased effort level may affect individual fishing areas. Since harvest levels in area 1A are most likely to reach the respective

Table 5
Share of predicted harvest by gear type—maximum effort

Gear type	Predicted harvest
Trawl	264,384
Purse seine	63,019
Weir	7.14
	327,410

Table 6
TACs for the 2005 fishing year

Area 1A	Area 1B	Area 2	Area 3	U.S. Total	NB Fishery	Total
60,000	10,000	50,000	60,000	180,000	20,000	200,000

Source: Revised FMP specifications 2005.

total allowable catch, special attention must be given to this area. In the 4 years considered in this analysis, landings in area 1A have averaged 55.75% of the total annual landings. In the same time period, purse seine landings have accounted for roughly 30% of the total catch taken from area 1A [3]. Because the purse seine vessels are typically restricted to fishing exclusively in this area, an increase in effort level as above would dramatically increase the inefficiencies resulting from the race to fish already occurring here. These pressures are likely to exacerbate existing tension between participant groups and regional interests.

The motivation to amend the existing herring FMP was largely due to many subjective (and a few objective) claims of excess capacity in the industry.[13] The menu of alternative limited entry plans, as well as the purse seine/fixed gear-only fishing areas proposed by the council and advisory committees, were developed in part because many of the existing stakeholders foresaw potential problems due to existing overcapitalization and the threat of new entrants.[14] In the words of Al West from Stinson Seafood [13],

> "Limited access—we firmly believe that this has to happen. There is enough capacity in the fleet right now to take all of the quotas in all of the areas if the fish were there. There is no question in my mind that there is plenty of capacity."

The objective of limited entry schemes is to cap or reduce the amount of capital in the fishery. These programs, however, do not limit the level, intensity, or concentration

[11] Personal communication with Kohl Kanwit; Drew Kitts; Marybeth Tooley; and Lori Steele.

[12] Much of our technical advice came from Drew Kitz, Kohl Kanwit, and interviews of fishermen.

[13] The Environmental Impact Statement (EIS) includes estimates of capacity measures for individual vessels using data envelopment analysis (DEA). By sorting their 51 vessels into gear categories, they determined average vessel capacity and average trips taken per quarter for each gear type to arrive at an aggregate harvest estimate (current effort) of 180,100 mt. This analysis, however, does not allow for predictions using technical efficiency measures.

[14] See NEFMC July 13th, 2004 meeting minutes discussing Amendment 1 to the herring FMP.

of effort individual fishers may exert in the fishing year. Therefore, limited entry programs are unsuccessful at preventing derby fishing, because the remaining vessels are competing against each other to capture the largest share of the given quota [23]. An increasingly important alternative is a system of individual quotas, which can be traded across participants.

6.2. Individual tradable quotas (ITQs)

By issuing defined property rights, ITQs should result in an increase in economic efficiency [7–9,24]. These gains, at least in theory, are realized for two reasons. First, relatively inefficient vessels will find it more profitable to sell their entire quota and leave the industry as opposed to continuing fishing. Meanwhile, the remaining fishermen can buy or sell quota until each equates its marginal benefit from fishing to the market permit price. Under the assumptions of complete information, perfect competition, and zero transactions costs and the additional assumption that the distribution of quotas does not affect the marginal valuation of the resource, the resulting distribution of fishing effort will be efficient [9].

Increased efficiency can be caused by reducing technical, allocative, or scale inefficiencies. Allocative inefficiency describes a choice of inputs that does not minimize the cost of producing a given output, while scale inefficiency describes an inappropriate choice of output for a given technology [9]. Due to a lack of cost data, our analysis focuses on management impacts on technical inefficiencies. We proceed under the assumption that the most technically efficient boats will also be the most cost effective—an assumption in keeping with the previous economic literature evaluating gains from ITQs [8,25]. For our study, this assumption is reasonable because we consider capital to be fixed in the short run, while vessels are choosing a single variable input (days fishing).[15]

We can now use our technical efficiency estimates to predict which vessels will remain in the fishery under a fully functioning ITQ system. To proceed, we abstract from the many details involved in designing and implementing an ITQ regime and only focus on long-run capital restructuring. For simplicity, we can assume that individual quotas are grandfathered to all licensed vessel owners free of charge as is typically the case in the US [10]. In addition we will consider the aggregate TAC to be fixed at 180,000 mt annually.

We examine two scenarios. First determine the most efficient fleet structure needed to harvest the current annual market demand of roughly 100,000 mt. Second, we find the most efficient fleet structure needed to harvest the total allowable catch of 180,000 mt. We can then analyze the predicted distributional impact of the ITQ plan on gear class, contract type, home port state, and vessel size. These variables are particularly important because they identify the primary stakeholders in the Atlantic herring fishery. Essentially, we are determining which industry groups will win or lose given a particular policy decision.

A graph of harvest as a function of fleet size (assuming maximum effort) is shown below in Fig. 1.

The graph shows the cumulative harvest levels (y-axis) given various fleet sizes, where the fleet is ordered from the most to the least technically efficient vessels (x-axis). If the economic predictions are realized, less efficient vessels will choose to sell their share of the quota to more efficient fishers, rather than to continue harvesting. Therefore, in the long run, the ITQ system selects the most efficient vessels to remain in the fishery. The graph is useful for determining the long-run fleet size needed to harvest a given level of catch.[16]

The lower arrow suggests that while 54 boats have been active (at least minimally) in the previous four years, a fleet less than 1/3 of that size could harvest the same amount at a more efficient level. Although the assumptions required to achieve maximum efficiency under an ITQ system are restrictive, we can expect to see a substantial exit of capital from the industry in the long run. The second arrow indicates that only the 23 most efficient vessels are needed to harvest the TAC. This point represents the fleet structure that would result were market demand to increase to consume the entire TAC.[17]

Table 7 shows the predicted distributional impact of an ITQ regime given current and increased market demand for herring.

Given the current total harvest, an ITQ system would produce further domination by single and pair-trawl vessels compared to purse seine vessels. Independent vessels continue to account for the majority of the harvest, but lose a significant share of the total as demand increases. Processor contracted vessels, the least efficient in terms of contract type, are forced out of the fishery under the existing demand simulation, but account for over 20% of the catch given increased demand. Bait-company-contracted boats gain a significant share of the harvest relative to the status quo under current demand but do not increase their existing share if there is an increase in demand. A significant shift in the harvest from Maine to Massachusetts would result from the introduction of property rights,

[15] Logbook data indicate that vessels rarely vary the number of crew per fishing trip, and therefore we fix the crew level at its average level.

[16] *Note*: The flatter portions of the cumulative harvest graph indicate smaller boats fishing a relatively limited number of days. Specifically, the 1st, 3rd, and 8th most efficient vessels are in the smallest size class and therefore our analysis assumes they are unable to increase their current effort levels (1, 4 and 80 fishing days respectively). The flat portion of the graph located between the 4 and 5 vessel indicates only a slight increase in cumulative harvest caused by the 5 most efficient boats. This vessel is in the second smallest size class (32 GRT) and employs only a single crew member and therefore its contribution is relatively small.

[17] It is likely that the few, very efficient smaller boats that fish a limited number of days are not significant players in the herring fishery. However, because those vessels are not capturing large shares of harvest, their presence has little impact on the shares of harvest for the remaining vessels.

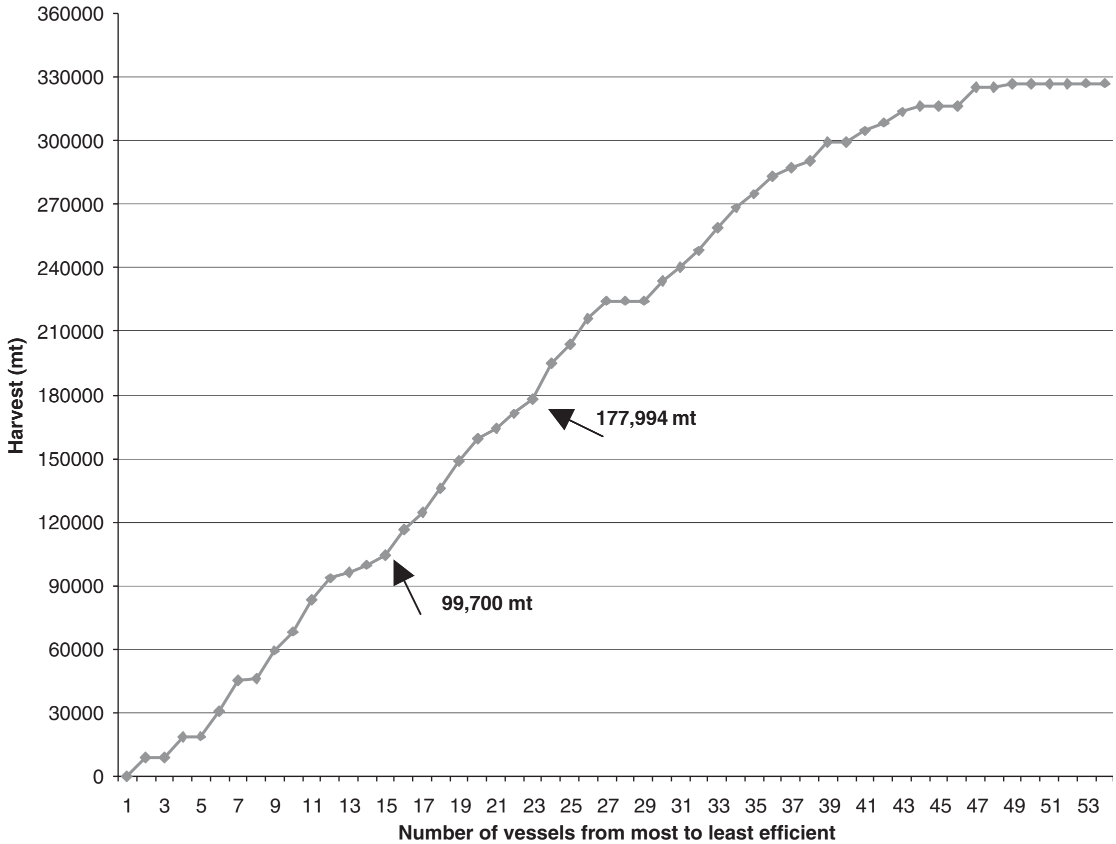

Fig. 1. Predicted harvest given most efficient fleet size.

and could have serious impacts on both states' lobster industries.

The processors who have established exclusive contracts with vessels will most likely support a tradable permit system only in the event of an increase in demand. Under the current market conditions, their relatively inefficient vessels will be unable to remain in the fishery. The bait-contracted boats, on the other hand, do not suffer significant losses under either scenario but capture a much larger percentage if demand stays at its current level. We should therefore expect the bait dealers with dedicated boats to favor an ITQ system in the absence of a change in the market.

We do not see a dramatic change in harvest percentage by vessel weight in either scenario. The relatively efficient large boats see a small increase given a positive shock in demand while the medium boats capture just slightly less. However, it is important to note that purse seine fishermen tend to use smaller boats and are restricted to the inshore area. Although they are the most efficient gear type, they are also likely to have already reached their technical constraint on harvest capacity. Therefore, an increase in demand in conjunction with individual quotas will necessarily reduce the purse seine harvest percentage.

These simulations paint a quantitative picture of the likely impact of ITQs in the Atlantic herring fishery. Although that impact will depend in part on the total catch as determined by market demand, policymakers can make detailed predictions of how policy change will affect the distribution of the catch across different stakeholders in the fishery. If demand grows, the total allowable catch will eventually determine the number of vessels that can remain in the fishery as well as the distribution of benefits.

7. Conclusion

Individual tradable quotas are an increasingly important policy option for fisheries management. While a handful of papers have explored the impact of implementing an ITQ program *ex post*, this study uses an objective econometric approach to predict how individual property rights would change the composition of the fishing fleet and the distribution of the harvest over that fleet. These results will help the management of the Atlantic herring fishery forecast the long-term distributional and efficiency impact of a property rights regime; in addition, this approach could be used to simulate the effect of policy change in other fisheries, giving policymakers a valuable analytical tool.

It is important to emphasize the objective nature of this study. These simulations are useful in predicting who wins

Table 7
Distributional effects of ITQs on harvest percentage

	Current demand (100,000 mt)		Increased demand (180,000 mt)
	% of Harvest under existing management	% of Harvest under ITQ management	% of Harvest under ITQ management
Gear type			
Purse seine	22%	4.33%	8.65%
Trawl	78%	95.67%	91.35%
Weir	.001%	0	0
Home port state			
MA	33%	55.52%	51.17%
ME	44%	35.62%	26.17%
NH	6%	8.86	9.68%
NJ	8%	0	7.67%
RI	9%	0	5.31%
Contract type			
Processor contracted	10%	0.00%	22.68%
Bait company contracted	14%	23.61%	13.23%
Independent	76%	76.39%	64.09%
GRT			
Low (Q1)	3.00%	4.34%	2.43%
Medium (Q2 & Q3)	56.6%	55.86%	55.02%
High (Q4)	40.4%	39.80%	42.55%

Note: "Low", "Medium" and "High" gross registered tonnage refers to the first quartile, the middle quartiles and the fourth quartile, respectively, for vessels in the data set.

and who loses from an ITQ regime, but they do not consider the important equity concerns that surround this issue. Our finding that the purse seine fleet will continue to lose a substantial percentage of the total annual harvest under ITQs should be considered in evaluating policy options including alternatives to ITQs.

This study also confirms what fishermen and industry stakeholders have been claiming for years: there is substantial overcapitalization in the Atlantic herring fishery. A fleet roughly one-third its current size could harvest the current demand for herring at a much more efficient level, and only 23 vessels are necessary to harvest the total allowable catch. Right now, fishing effort is primarily regulated by the market (demand for herring), but the capacity is in place to accommodate a large increase in the demand for herring. To reiterate Dan Axelsson's statement during a 2003 scoping meeting, "It's been the markets that have regulated our participation, but change is in the wind." Demand pressure from the American lobster fishery and the various domestic and international export markets could produce significant increases in fishing effort, leading to increased inefficiency and potential overfishing. For these reasons, addressing the excess capacity problem is of tantamount importance in achieving a sustainable commercial herring fishery.

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