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Total Factor Productivity Change in the New England Groundfish Fishery: 1964–1993[1]

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We develop estimates of total factor productivity (TFP) change in the New England groundfish fishery from 1964 to 1993, using a procedure similar to Squires' (1992, *Rand J. Econom*. **23**(2), 221–236) method, which extends standard TFP measurement by including the effect of fluctuations in stock abundance. The results indicate that TFP increased on average by 4.4% per year from 1964 to 1993. A higher average rate of increase occurred between 1964 and 1982, possibly due to new technologies (e.g., fishfinders). TFP declined at 0.33% annually from 1983 to 1993 due to stringent output and effort control measures. © 2002 Elsevier Science (USA)

Key Words: commercial fishing; total factor productivity; fisheries management.

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1. INTRODUCTION

Productivity change is an important indicator of an industry's performance. Understanding productivity change is very important to fisheries management [31] since productivity allows fisheries to become more competitive but also places additional harvest pressure on fish stocks. Because it is not a measurable input or output and is virtually impossible to control, productivity growth adds considerable complication to fisheries management. Productivity measurement can provide useful information about effective fishing effort, as opposed to nominal measures of effort such as catch per day at sea [31].

In this paper, we examine productivity in New England otter trawl fisheries. Otter trawl gear[2] is the dominant means for harvesting groundfish in this region. We selected the New England groundfish fishery for three reasons. First, there has been no long-term quantitative analysis of productivity change in the fishing industry because of data problems. For most fisheries, long-term historical stock data do not exist. New England fishing grounds have been among the most productive in the world, and historical landings, effort, and stock data have been well documented, which makes our study feasible.[3] Second, over the period of analysis (1964–1993) the fishery was open access. The industry's performance depends on the abundance of the stocks of commercially valuable species. By including the stock factor, we are able to examine the effect of changing resource conditions on the groundfish industry's productivity. Finally, the industry has experienced substantial changes in management institutions and regulatory instruments in the past 30 years.

Prior to the establishment of the Exclusive Economic Zone (EEZ) in 1977, the New England groundfish fishery was essentially unregulated. Productivity change during this period may be expected to have been largely influenced by market-driven factors. From 1977 to 1982 the fishery was managed under output quotas for the three most important species: cod, haddock, and yellowtail flounder. Under quota management, investment and fishing decisions were distorted by incentives to take quotas as quickly as possible. Dissatisfaction with quota management led to its abandonment in 1982 in favor of indirect effort controls such as minimum fish sizes and fishing gear restrictions. Although input controls are designed to reduce fishing mortality, they generally do so by inhibiting the efficiency of fishing technology. Thus, the study period covers three distinct periods representing watershed changes in management that may have important implications for productivity change in the New England groundfish fishery. By estimating the changes in total factor productivity during this period, we can draw inferences about regulatory impacts on the industry.

The remainder of this paper is organized as follows. Section 2 presents the methodology used to develop total factor productivity estimates. Section 3 describes the fishing industry as well as data sources and compilation processes.

[2] The otter trawl is an underwater net with one closed end (known as the cod end) and one open end acting as a giant mouth, capturing all fish in front of the net. At the sides of the net are flat "wings" or trawl doors, often metal pieces, designed to spread the net's opening or "mouth" to its maximum as it is pulled through the water column. To determine where in the water column the net fishes, weights or bars are added to, or removed from, the front of the net.

[3] We understand that our data do not capture undocumented landings which may be significant (John Tarasevich, personal communications).

Estimation results are presented in Section 4. Section 5 discusses the management and technical factors affecting changes in productivity. Conclusions and summaries are included in Section 6.

2. METHODS

In this study, we use a procedure developed by Squires [30] to estimate changes in total factor productivity (TFP) in a fishery. Although a limited access program was implemented in 1994, the New England groundfish fishery had been open access prior to that time. Under open access, subject to certain requirements, vessels can enter (and exit) a fishery at will. Individual producers do not control stock size. In the single output case, the harvest function (see Clark [4]; Anderson [1]; Hannesson [15]) is often defined as

$$Y = qA(t)F(X_1, \dots, X_n)B, \tag{1}$$

where Y is output, q is the catchability coefficient, F is the production function, X_j $(j = 1, \dots, n)$ is input j, B is stock size, and $A(t)$ measures the cumulative effect of shifts in the production function over time (t), or total factor productivity (TFP). $A(t)F(X_1, \dots, X_n)$ may be considered as the effective fishing effort. Equation (1) is an extension of Solow [32]. If q is a constant,[4] a change in TFP is given by

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum e_{X_j} \frac{\dot{X}_j}{X_j} - \frac{\dot{B}}{B}, \tag{2}$$

where e_{X_j} is the elasticity of output with respect to input X_j.[5] Note that the third term on the right-hand side captures the stock fluctuations. That is, the changes in productivity are explained not only by changes in output and input levels, but also by changes in stock size.

Equation (2) is the fundamental equation of growth accounting in its continuous time, Divisia index form [17]. In empirical practice, the continuous growth rates can be replaced by Tornqvist approximations [16].

Because the New England groundfish fishery is a multispecies fishery, we have outputs of m species (Y_i, $i = 1, \dots, m$) and n inputs (X_j, $j = 1, \dots, n$). The price of Y_i is p_{Y_i} and the cost of X_j is p_{X_j}. The Tornqvist approximation of (2) is

$$\begin{aligned} \ln\left[\frac{A(t)}{A(t-1)}\right] &= \frac{1}{2} \sum \left[S_{Y_i}(t) + S_{Y_i}(t-1)\right] \ln\left[\frac{Y_i(t)}{Y_i(t-1)}\right] \\ &\quad - \frac{1}{2} \sum \left[S_{X_j}(t) + S_{X_j}(t-1)\right] \ln\left[\frac{X_j(t)}{X_j(t-1)}\right] \\ &\quad - \frac{1}{2} \sum \left[S_{Y_i}(t) + S_{Y_i}(t-1)\right] \ln\left[\frac{B_i(t)}{B_i(t-1)}\right] \end{aligned} \tag{3}$$

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[4] We will not examine the effect of changing catchability due to lack of data. For different forms of production functions in fisheries, see Hannesson [15].

[5] Since e_{X_j} is not observed, it cannot be used for empirical analysis. Usually, we assume that factor inputs are paid the value of their marginal product [32]. Conrad *et al.* [5] showed that although in fisheries crew and captain were compensated through a “lay system” (see footnote 8), they did receive approximately the value of their marginal products.

with

$$S_{Y_i} = \frac{p_{Y_i} Y_i}{\Sigma p_{Y_i} Y_i}, \qquad S_{X_j} = \frac{p_{X_j} X_j}{\Sigma p_{X_j} X_j}, \tag{4}$$

where S_{Y_i} is the revenue share of species i, S_{X_j} is the cost share of factor j, and B_i is the abundance of the stock of species i.

The last term in (3) represents changes in stock abundance. As explained by Squires [30], the productivity residual is biased without disentangling variations in stock (B). In a normative analysis such as a social planner's problem, there is a sole owner (planner), and B is one of the control variables. B_i should then be weighted by the cost share of the stock of species i based on its shadow value. In contrast, our approach is a positive analysis of an open-access fishery, B is not a decision variable of fishing firms, and proportional changes in abundance are simply pared away from the conventional productivity residual without weighting by cost shares. The stock abundance of species i (B_i) is weighted by the corresponding revenue share associated with Y_i. Thus, in developing an aggregate stock index, species with higher value get greater weight. After accounting for the stock effect, the residual may be explained by other factors, such as regulatory impacts and technical change.

Equation (3) does not include the production of the foreign fleet that harvested a significant portion of some New England groundfish stocks before 1976. This may create a bias in our TFP estimates for that period. However, explicit inclusion of the foreign fleet is not feasible due to lack of economic data.

During our study period, the groundfish fishery was a regulated industry. Both inputs and outputs were controlled by various regulations. Several factors may significantly affect the productivity of a regulated industry: economies of scale, biased technical change, nonmarginal cost pricing, and capacity utilization, among others [6]. Using a cost function approach, Denny *et al.* [8] have demonstrated that TFP may be decomposed to separate the effects of technical change (shift in the cost function), scale economies (moving along the cost function), and nonmarginal cost pricing. We are not able to estimate these effects explicitly here, since we do not have sufficient cost information.

Capacity utilization is an additional source of variation in output, which might be attributed to TFP growth if not recognized and treated specifically [20]. Capacity utilization based on an economic definition of capacity[6] has been addressed in a number of studies [3, 16]. When the actual output is not equal to capacity output, the cost of quasi-fixed inputs (p_X) should be adjusted, and corresponding shares (S_{X_j}) should be changed.

In our study, we first develop TFP estimates with the use of Eqs. (3) and (4). We then perform sensitivity analyses to address the issue of capacity utilization. Specifically, we develop another set of TFP estimates with an approach described by Hulten [16]:

$$\frac{\dot{A}^H}{A^H} = \left[\frac{\dot{A}^0}{A^0} + \theta\left(\frac{\dot{Y}}{Y} - \frac{\dot{X}_K}{X_K}\right)\right] \Big/ (1+\theta) - \frac{\dot{B}}{B}, \tag{5}$$

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[6] In contrast, there is a technological-engineering definition of capacity [11]. For an excellent discussion of the two capacity definitions and an application of the technical-engineering approach to fisheries research, see Kirkley and Squires [19].

where $\theta = (p_Y Y - C)/C$ is the percentage difference between revenue $(p_Y Y)$ and short-run cost (C), X_K is the quasi-fixed input, and

$$\frac{\dot{A}^0}{A^0} = \frac{\dot{Y}}{Y} - \frac{\dot{X}}{X} \tag{6}$$

is the TFP estimate, assuming that $\Sigma p_{X_j} X_j$ in (4) represents long-run cost.

According to Hulten [16], with capacity under- or over-utilization, the total cost reflects short-run cost and not long-run equilibrium cost. The short-run cost captures capacity utilization and inefficiency in production. Thus, Eq. (5) provides TFP estimates corrected for both capacity utilization and stock effects.

3. INDUSTRY AND DATA

To estimate the changes in total factor productivity in fisheries, three sets of data are required: output quantity (Y) and value (p_Y) by species; factor input quantity (X) and cost (p_X) (such as vessel cost); and stock size (B). The industry consists of fishing firms (vessels). While industry output data are relatively easy to obtain, input cost data are not available for all vessels in all years. Our cost data are generated through a hedonic cost function approach [18] and by combining cost information for different periods from several sources.

3.1. *Species*

To develop systematic estimates of productivity changes in the New England groundfish fishery during the 1964–1993 period and to make data processing manageable, we selected 13 representative groundfish species based on their current and historical contributions to the total value of groundfish landings and on data availability [23]. The 13 groundfish species are listed in Table I, with average revenue shares in four different time periods.

TABLE I

Average Revenue Shares[a]

Species	1964–1973	1974–1983	1984–1993	1964–1993
Cod	0.125	0.221	0.281	0.209
Winter flounder	0.096	0.110	0.134	0.113
Summer flounder	0.010	0.039	0.064	0.038
Witch flounder	0.027	0.039	0.073	0.046
Yellowtail flounder	0.261	0.225	0.134	0.207
American plaice	0.022	0.072	0.088	0.060
Windowpane flounder	0.000	0.008	0.024	0.011
Haddock	0.266	0.134	0.059	0.153
Red hake	0.001	0.003	0.003	0.003
White hake	0.006	0.010	0.027	0.015
Redfish	0.099	0.061	0.013	0.058
Pollock	0.020	0.038	0.053	0.037
Silver hake	0.068	0.039	0.046	0.051
Sum	1.000	1.000	1.000	1.000

[a] Percentage of total revenue by each species (average over each period).

We are confident that our productivity analysis based on these 13 species captures the trend of productivity growth in the New England groundfish fishery as a whole, since the analysis includes all major species examined by previous studies [10, 29]. Nevertheless, exclusion of other species from the study may lead to biases in our estimates.

3.2. *Outputs and Inputs*

Output and input data for the 13 groundfish species were extracted from the Commercial Fisheries Database System maintained at the National Marine Fisheries Service Northeast Fisheries Science Center [26]. There have been some changes in data format and coverage during the study period. For example, the database coverage has expanded from only three states in the 1960s to 11 states in the 1990s. Also, the number of variables describing specific features of each fishing trip (e.g., vessel, gear, and operation) has been expanded since 1982. We used three sets of NMFS data: 1964−1981 trip-level output and input data, 1982−1993 trip-level output data, and 1982−1993 trip-level input data. The last two data sets were merged by trip identification numbers.

For the 30-year period, complete data were usable for three New England states: Maine, Massachusetts, and Rhode Island. Thus, our sample included information pertaining to all trips registered at ports in these three states. The output variables were quantity and value of landings of the 13 species in each trip. The output data were aggregated into annual measures of quantity and value by species. The values were converted to 1993 dollars by using chain-type price indices for gross domestic product. To develop corresponding input estimates, we used three variables: vessel identification number, vessel tonnage class, and the number of days absent from port for a fishing trip. This enabled us to construct aggregate measures of the number of vessels in each tonnage class by year, and the number of days absent by tonnage class and by year. Following the NEFSC [23], tonnage class was broken down as follows: Class 1: vessels under five tons, Class 2: vessels between five and 50 tons, Class 3: vessels between 51 and 150 tons, and Class 4: vessels above 150 tons. Prior to 1994, fishing activity for Class 1 vessels was not reported on an individual vessel basis. Therefore, data for Class 1 vessels were excluded from the analysis.

Between 1964 and 1975, landings declined by 54%, largely because of overfishing by foreign vessels (Fig. 1). Landings subsequently increased until 1982 and then markedly declined by 59% between 1982 and 1989. The highest (437 million pounds) and lowest (103 million pounds) landings occurred, respectively, in 1964 and 1993. Ex-vessel (first sale) value declined by 33% from 1966 to 1971 and by 51% from 1982 to 1993. Since 1975, trends in quantity and value have been similar. Of the 13 groundfish species, the most important in terms of quantity of landings were cod, yellowtail flounder, silver hake, redfish, haddock, and winter flounder. In terms of revenue, the most important species were cod, yellowtail flounder, winter flounder, haddock, and American plaice (see Table I).

Between 1978 and 1983, vessel numbers increased in all three tonnage classes, with the greatest increase in the larger vessel size categories (Fig. 2). For example, the number of Class 4 vessels nearly tripled from 39 in 1978 to 107 in 1982. As new vessels entered the fleet, new technologies were introduced into the industry.

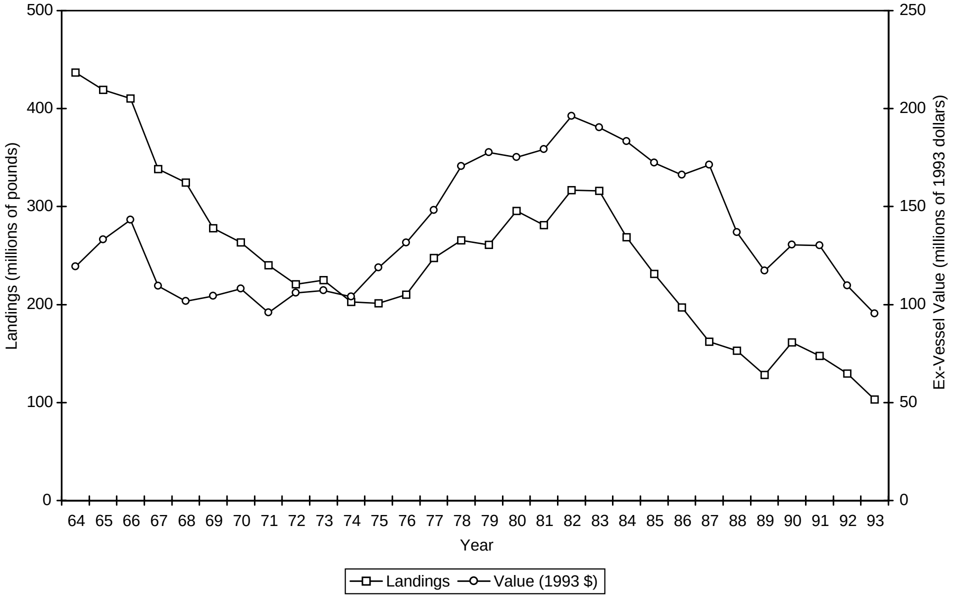

FIG. 1. New England groundfish landings (13 species) and ex-vessel value, 1964–1993.

This fishing fleet expansion resulted from a combination of factors, among which were favorable resource conditions and the exclusion of the foreign fishing fleet from fishing for New England groundfish under the Magnuson–Stevens Fishery Conservation and Management Act of 1976, which took effect in 1977. Fleet expansion was also fueled by favorable economic conditions as seafood demand

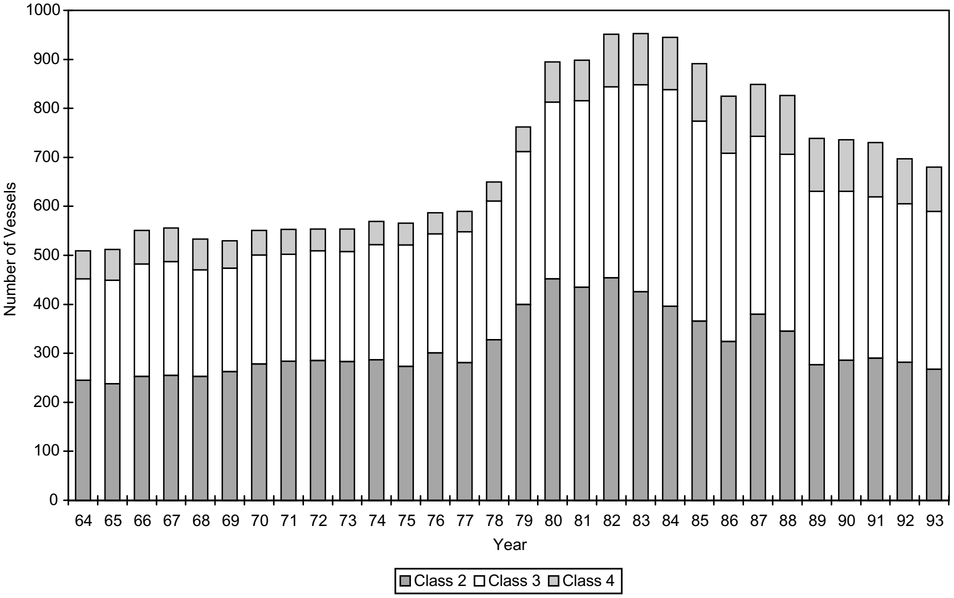

FIG. 2. Number of New England otter trawl vessels by tonnage class, 1964–1993.

increased through much of the late 1970s and mid-1980s. This expansion was assisted by government policies subsidizing the development of the U.S. fishing industry [13].

The total number of days absent by all vessels increased by 54% between 1977 and 1985 (Fig. 3). The number of days absent for Class 4 vessels nearly tripled from 6,219 days in 1977 to 17,342 days in 1986. Most of the increase was associated with the increased number of vessels.

A small number of observations were deleted from the data to ensure that output matched input. In most cases, an observation was trimmed due to missing data for one of the output or input variables. In other cases, observations were deleted if they were considered outliers for this study.

3.3. *Costs*

A complete time series of cost data for the study period was not available. Many previous studies employed some type of equilibrium assumption and derived costs from revenue data [10]. Other studies developed estimates for major cost components, such as labor, fuel, and vessel, using data from the Bureau of Labor Statistics [30]. There are several historical cost and earnings studies for the New England groundfish fishery. For example, the National Marine Fisheries Service [21] reported cost and earnings data. Also, Crutchfield and Gates [7] examined costs and returns between 1976 and 1982.

In this study, cost estimates were generated by an approach that integrated available historical cost information from several sources for different periods. Survey data for 1964 to 1968 were published by the National Marine Fisheries Service [21]. Data for 1974 can be found in another NMFS publication [22]. We

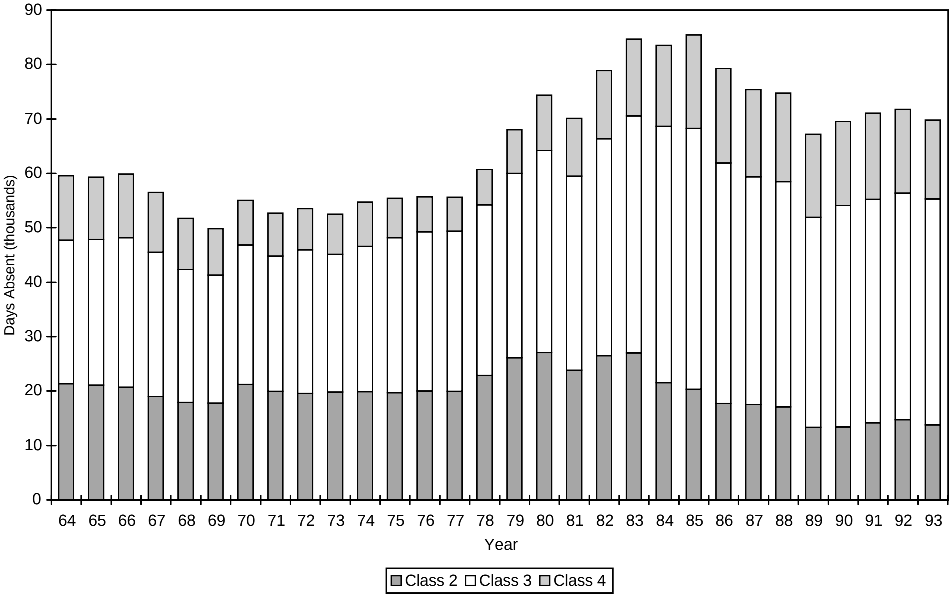

FIG. 3. Number of days absent by tonnage class, New England otter trawl vessels, 1964–1993.

obtained survey cost data for 1976 to 1981 from the Northeast Fisheries Science Center (NEFSC) at Woods Hole. Capital construction fund (CCF) data [14] from 1982 through 1993 were also utilized.

As data from different years were compiled from surveys of vessels of different sizes and using different cost item definitions, we developed cost estimates by a hedonic cost function approach [18], where cost is a function of vessel characteristics, including gross tonnage (grt), length, horsepower (hp), age, and year.[7]

$$\mathrm{FC} = f(\mathrm{grt}, \mathrm{hp}, \mathrm{age}, \mathrm{year}) \tag{7}$$

$$\mathrm{VC} = g(\mathrm{hp}, \mathrm{age}, \mathrm{year}) \tag{8}$$

$$\mathrm{LC} = h(\mathrm{grt}, \mathrm{length}, \mathrm{hp}, \mathrm{year}). \tag{9}$$

Here FC is the annual fixed cost per vessel; VC is the variable cost per vessel per day absent; and LC is the labor cost per vessel per day absent. The labor cost is crew share and other relevant costs in a lay share system.[8]

To develop cost functions, we first group individual cost items from historical surveys into annual fixed cost (FC), variable cost per day absent (VC), and labor cost per day absent (LC). Then, all costs are converted into 1993 dollars, using chain-type price indices for gross domestic product. Finally, different functional forms are tested to seek the best specifications, using model selection techniques such as the stepwise method. For the 30-year study period, we use three sets of models for three periods: 1964–1974, 1975–1981, and 1982–1993.[9]

As noted, for each year and vessel tonnage class, two variables affect fishing effort (in the production function): number of vessels and number of days absent.[10] To develop corresponding cost estimates, we calculated the number of days absent for each vessel in each year. Then, annual variable and labor costs were generated for each vessel. Finally, total annual fixed, variable, and labor costs for a tonnage class were calculated as the sum of vessel-level costs in that class.

Data gaps were bridged using cost indices from government agencies. Norton *et al.* [25] argue that the rate of change for all cost components except fuel and interest can be represented by the Bureau of Labor Statistics (BLS) producer price index for industrial commodities. The change in interest rate can be represented best by the prime rate for short-term business loans. Fuel price changes can be represented by the BLS producer price index for petroleum products. Based on NMFS cost data, fuel cost accounts for 50% of variable costs and interest accounts for 30% of fixed costs. Like Norton *et al.* [25], we assumed that the wage rate could be represented by the producer price index for industrial commodities, which has a lower rate of increase than the wage rate in manufacturing.[11]

Fixed, variable, and labor cost shares for the groundfish fishery from 1964 to 1993 are shown in Table II. At the fleet level, the labor cost share is the largest,

[7] Information on vessel characteristics was obtained from NMFS.

[8] Each trip's gross revenue is divided among vessel (maintenance and owner), captain, and crew according to fixed percentages. Trip expenses (e.g., fuel, food, and ice) are paid out of the crew's share; what is left after expenses becomes the crew's wages.

[9] Specific cost functions for different years are described in a working paper by the authors and available upon request.

[10] Ideally crew should be treated separately. Unfortunately, this was not possible due to lack of data.

[11] Terkla *et al.* [33] have shown that there can be substantial labor stickiness in the core New England fishing industry.

TABLE II

Cost Shares: 1964–1993[a]

Year	Fixed	Variable	Labor	Sum
1964	0.314	0.300	0.387	1.000
1965	0.283	0.277	0.440	1.000
1966	0.292	0.257	0.451	1.000
1967	0.298	0.229	0.473	1.000
1968	0.313	0.214	0.474	1.000
1969	0.331	0.211	0.458	1.000
1970	0.317	0.218	0.466	1.000
1971	0.294	0.228	0.478	1.000
1972	0.150	0.264	0.585	1.000
1973	0.157	0.271	0.572	1.000
1974	0.147	0.294	0.559	1.000
1975	0.184	0.221	0.595	1.000
1976	0.185	0.243	0.573	1.000
1977	0.190	0.267	0.543	1.000
1978	0.187	0.296	0.518	1.000
1979	0.193	0.321	0.486	1.000
1980	0.206	0.348	0.446	1.000
1981	0.214	0.374	0.412	1.000
1982	0.423	0.274	0.303	1.000
1983	0.395	0.286	0.320	1.000
1984	0.363	0.295	0.342	1.000
1985	0.316	0.312	0.372	1.000
1986	0.297	0.318	0.385	1.000
1987	0.303	0.320	0.378	1.000
1988	0.288	0.325	0.388	1.000
1989	0.272	0.328	0.401	1.000
1990	0.248	0.336	0.417	1.000
1991	0.237	0.341	0.423	1.000
1992	0.207	0.351	0.442	1.000
1993	0.202	0.355	0.444	1.000
Mean	0.260	0.289	0.451	1.000

[a] Percentage of total cost by cost component and by year.

averaging 0.45 over the 30-year period. On average, the variable cost share (0.29) is slightly greater than the fixed cost share (0.26).

3.4. *Fish Stocks*

NMFS research vessel survey abundance indices (i.e., mean number of fish per tow or mean weight per tow) for the 13 groundfish species were used as proxies for stock size.[12] The survey abundance indices are total catch per tow and are relative measures of total biomass. While TFP is derived from the harvestable portion of the biomass, the two measures (total and harvestable), as well as spawning stock biomass, are highly correlated. As such, use of a total biomass index probably does not seriously bias the results.

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[12] The NEFSC spring and autumn surveys cover the entire Northeast continental shelf. Therefore, the New England groundfish catch-per-tow data include southern New England, Georges Bank (i.e., U.S. and Canadian portions), and the Gulf of Maine.

FIG. 4. Trends in aggregate stock biomass for New England groundfish, 1964–1993.

NMFS survey data were weighted by survey area to account for differences in abundance of the same species across differing stock areas. Abundance indices for 12 of the 13 species (all except summer flounder) were based on 1964–1993 NMFS autumn survey mean weight per tow values.[13] For summer flounder, spring survey mean weight per tow indices from 1968–1993 were used [24]. The summer flounder abundance indices during 1964–1967 were extrapolated using regression techniques.[14]

Although the abundance indices are weighted by revenue shares of corresponding species in the TFP analysis, the sum of the NMFS survey abundance indices provides a better indicator of resource conditions over the period of analysis (Fig. 4). Groundfish stocks declined over the study period. By 1990–1992, fishing mortality rates for the three major groundfish species (cod, haddock, and yellowtail flounder) were twice as great as the management targets [2].

4. RESULTS

The total factor productivity change in the New England groundfish fishery without accounting for stock effects is shown in Table III in the column headed O–I (Output–Input). This is the Tornqvist change chain index estimated using the first two terms in Eq. (3). Most years are negative, except 1973, 1975–1977, 1980, 1982, and 1990. From 1975 to 1977, both output and value increased (Fig. 1), while effort (e.g., U.S. fleet size) remained relatively constant. The largest increases in number of vessels (Fig. 2) and days absent (Fig. 3) occurred between 1977 and 1980. The largest reductions in TFP (24.8% and 21%), caused by marked declines

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[13] The data were provided by Wendy Gabriel and Katherine Sosebee in personal communications.

[14] Abundance indices of haddock are used as the independent variable, since the two stock indices are correlated.

TABLE III

Tornqvist Change Indices: 1964–1993[a]

Year	Output	Input	O–I	Stock	TFP	$\mathrm{TFP}^{\mathrm{H}}$
1965	−0.015	0.001	−0.016	−0.336	0.320	0.328
1966	−0.041	0.033	−0.074	−0.385	0.311	0.325
1967	−0.185	−0.036	−0.149	−0.064	−0.085	−0.079
1968	−0.098	−0.094	−0.004	−0.129	0.126	0.127
1969	−0.144	−0.053	−0.091	−0.143	0.052	0.052
1970	−0.108	0.035	−0.144	0.064	−0.208	−0.207
1971	−0.121	−0.025	−0.096	−0.321	0.225	0.225
1972	−0.128	0.004	−0.131	0.381	−0.512	−0.517
1973	−0.018	−0.020	0.002	−0.404	0.407	0.415
1974	−0.034	0.050	−0.084	−0.441	0.357	0.349
1975	0.032	−0.002	0.034	0.144	−0.110	−0.108
1976	0.023	−0.014	0.037	0.275	−0.239	−0.225
1977	0.194	0.000	0.194	0.078	0.116	0.125
1978	0.036	0.073	−0.037	0.034	−0.071	−0.075
1979	0.043	0.132	−0.088	−0.134	0.045	0.051
1980	0.141	0.134	0.007	−0.049	0.056	0.086
1981	−0.045	−0.026	−0.019	−0.019	−0.001	0.017
1982	0.130	0.111	0.018	−0.407	0.425	0.417
1983	0.000	0.053	−0.053	−0.033	−0.019	−0.029
1984	−0.236	0.013	−0.248	−0.347	0.099	0.098
1985	−0.196	0.010	−0.205	−0.146	−0.059	−0.083
1986	−0.208	−0.065	−0.143	−0.056	−0.087	−0.084
1987	−0.199	−0.042	−0.156	−0.458	0.301	0.315
1988	−0.057	−0.003	−0.054	0.206	−0.260	−0.256
1989	−0.207	−0.089	−0.118	−0.079	−0.039	−0.041
1990	0.192	0.025	0.168	0.030	0.138	0.106
1991	−0.094	0.012	−0.105	−0.653	0.547	0.534
1992	−0.165	−0.008	−0.157	0.289	−0.445	−0.496
1993	−0.232	−0.021	−0.210	−0.107	−0.103	−0.101
Mean	−0.060	0.006	−0.066	−0.111	0.044	0.044

[a] Annual change chain indices. TFP is calculated with Eq. (3) and $\mathrm{TFP}^{\mathrm{H}}$ is calculated with Eq. (5).

in landings, occurred in 1984 and 1993. During 1965–1993 total factor productivity declined by 6.6% annually (Table III).

The evaluation of TFP without accounting for stock fluctuations generates biased results. Using (3), we developed an adjusted Tornqvist change index estimate (illustrated in Table III in the column TFP) that indicates an increase in TFP in about half of the years in the study period. Large increases in TFP are evident in 1965–1966 (32% and 31%), 1973–1974 (41% and 36%), 1982 (43%), 1987 (30%), and 1991 (55%), while significant reductions occurred in 1972 (51%) and 1992 (45%). Over the 1964–1993 study period, TFP increased annually by 4.4% when stock changes were taken into account, as opposed to a 6.6% annual reduction when changes in the resource stock were not considered.

Sensitivity analysis results are also included in Table III in the last column, $\mathrm{TFP}^{\mathrm{H}}$, which is developed using Eqs. (5) and (6). Equation (6) is the first two terms of Eq. (3), and X_K is constructed from vessel information. Comparing $\mathrm{TFP}^{\mathrm{H}}$ and TFP results shows only minor changes in individual years with the same 30-year average. Generally, the estimates from our sensitivity analysis were quite close to the initial stock-adjusted estimates.

TABLE IV
Mean Tornqvist Indices (%): 1964–1993

Period	Output	Input	Stock	TFP	TFP^H
1964–1976	−6.97	−1.01	−11.33	5.37	5.71
1977–1982	8.31	7.06	−8.27	9.51	10.36
1983–1993	−12.73	−1.07	−12.32	0.66	−0.33

We calculated average Tornqvist change indices corresponding to the three key groundfish management periods (Table IV). From 1964 to 1976, TFP increased by an average of 5.37% per year, while output and input dropped by 6.97% and 1.01% per year, respectively, and stock size declined by 11.33% per year. During 1977–1982, TFP increased by 9.51% per year, while output and input increased by 8.31% and 7.06%, respectively, and stock biomass declined by 8.27%. Between 1983 and 1993, TFP increased by 0.66% annually during a marked reduction in both output (12.73% per year) and stock abundance (12.32% per year).

The results of sensitivity analysis are shown in the last column of Table IV. After correcting for capacity utilization, TFP^H was slightly greater in the first two time periods, with a 5.71% (TFP^H) annual increase from 1964 to 1976 and 10.36% (TFP^H) annual increase from 1977 to 1982. In contrast, the average TFP^H declined by 0.33% per year from 1983 to 1993 as opposed to the positive TFP estimate (0.66) without the capacity utilization correction.

5. DISCUSSION

The changes in total factor productivity of a fishery are affected by changes in output (landings), inputs, and stock levels (Eq. (2)). Landings are determined by effective fishing effort and stock size (Eq. (1)). Inputs and outputs are regulated, and stock levels are reduced most notably by overfishing. Thus, changes in management and regulation influence TFP directly through inputs and outputs and indirectly through their effect on stocks.

The New England groundfish fishery resource has been overfished during two historical periods. The first period occurred during the early 1960s, when U.S. and distant water fleets, particularly factory trawlers from the Soviet Union, depleted the major stocks of haddock, cod, yellowtail flounder, and others. A second period of overfishing occurred during the 1980s, brought on by the U.S. fleet.

In addition, the U.S. fleet lost its access to ICNAF (International Convention for the Northwest Atlantic Fisheries) Subarea 4 in 1977, and to a portion of Georges Bank after the establishment of the Hague line in 1984. These two actions not only reduced domestic stock abundance but also the availability of fishery resources to New England trawl vessels.

Between 1964 and 1993, the management system for New England groundfish has evolved from relatively weak effort controls to reliance, at different times, on extensive output and input controls. Output controls include total allowable catch (TAC), while input controls include gear restrictions (e.g., minimum mesh size). Over the entire time period of our analysis, TFP increased, but none of the management approaches succeeded in stopping the decline in abundance of the most important stocks. By 1990–1992, fishing mortality rates for the three major groundfish species (cod, haddock, and yellowtail flounder) were twice as great as the management targets [2]. Decades of overfishing have resulted in the loss of billions of dollars to the New England economy; if groundfish stocks were rebuilt, the catch could increase significantly with lower effort [10].

Since the interim groundfish fishery management plan from 1982 to 1986, there has been a dramatic increase in regulatory activity. The Northeast multispecies fishery management plan was approved in 1986 and has since been amended 12 times. Management actions have imposed restrictions on trip limits, mesh size, and days at sea and enacted several area closures. Many, if not all, of these actions have resulted in regulated inefficiencies. These regulatory instruments played a significant role in the annual decline in TFP^H (TFP adjusted for stock and capacity utilization) from 1983 to 1993 (Table IV).

The other important factor affecting productivity growth is technical change. Serchuk and Wigley [28] note that technological innovations and changes in consumer preferences have strongly influenced commercial landing patterns. Innovative technologies such as fishfinders (1970s), on-board conveyers[15] (1970s), and electronic navigation (1980s) contributed to the TFP increase during 1964–1983 (Table IV). As previously noted, there was a marked increase in vessel numbers in all tonnage classes between 1975 and 1983 (Fig. 2). New technologies were introduced as new boats entered the fleet. Our long-term average TFP change estimate reveals a 4.4% annual increase (Table III), which is higher than the estimates of increase in catchability in the New England groundfish fishery by other researchers [10, 27].

In the study, we have used a Tornqvist index to estimate total factor productivity change. Tornqvist indices are very simple to compute and have been widely used in the literature [9, 30]. There are other indices that allow greater decomposition of TFP. A Malmquist index could be decomposed relative to technical change, efficiency change, and capacity utilization [11, 12, 19]. Future studies using Malmquist indices may link specific contributing factors (e.g., technology, efficiency, scale economy, and utilization) to changes in TFP.

6. CONCLUSIONS

New England groundfish fisheries have experienced significant changes in management institutions and instruments during the past 30 years. Declines in several important commercial fish stocks have heightened public debate over fisheries management. We have developed estimates for total factor productivity (TFP) change in the New England groundfish fishery from 1964 to 1993, using a procedure similar to Squires' [30] method, which extends standard TFP measurement by including the effect of changes in stock abundance.

Our study leads to two conclusions. First, as Squires [30] has shown, stock effects should be included in estimations of TFP changes in fisheries to avoid biasing the estimates. For example, our results indicate that without accounting for stock effects, on average, TFP declined by 6.6% annually over the 30-year period. When

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[15] The conveyer significantly improved on-board fish handling and sorting (John Tarasevich, personal communications).

stock variations are included, the 30-year average TFP change shows an annual increase of 4.4%. Sensitivity analysis suggests that the TFP estimates are quite robust. Correcting for capacity utilization and short-run disequilibrium, the estimates of total factor productivity ($\mathrm{TFP}^{\mathrm{H}}$) growth rate differ only slightly from our initial stock-adjusted estimates.

Second, productivity change may be affected by fishery management policy. Although the analytical methods employed herein do not permit explicit consideration of management effects, the relationship between productivity change and management regime is striking. From 1964 to 1976 productivity increased by 5.71%. This corresponds to a period of declining output but relatively little change in input in terms of both fleet size and effort (days absent). Productivity growth (10.36%) from 1977 to 1982 was almost double that of the previous time period, as both output and input increased substantially under a quota management regime. While other factors also played a role (fleet modernization, for example), quota management has provided a strong incentive to take fish as rapidly as possible. In contrast, input controls place constraints on the use of fishing technology. This effect is apparent in the stagnation in productivity growth from 1983 to 1993.

These observations should not be interpreted as suggesting that the quota management period of 1977 to 1982 was superior to that of input controls from 1983 to 1993; neither was able to forestall groundfish stock declines throughout both periods. The critical distinction between the two is that the input management regime (1983–1993) not only failed to conserve groundfish stocks, but also stymied productivity growth. Pursuit of a deliberate policy to stifle productivity (and hence income) growth would be difficult to justify in industries where property rights are fully specified, yet it is commonplace in fisheries.

Rising TFP leads to higher income to fishermen. Healthy resource conditions are a precondition for sustained increases in income and economic well-being. New England groundfish management policy from 1964 to 1993 was unable to strike a balance between productivity growth and resource health. Striking this balance is equally challenging today.

LIST OF SYMBOLS

Y	output
i	species index, $i = 1$ (one), $\ldots, m$
m	total number of species
Y_i	output i
j	input index, $j = 1$ (one), $\ldots$, n
n	total number of inputs
X_j	input j
e_{X_j}	elasticity of output with respect to input X_j
p_{Y_i}	price of Y_i
p_{X_j}	cost of X_j
S_{Y_i}	revenue share of species i
S_{X_j}	cost share of factor j
X_K	quasi-fixed input
p_Y	price of Y
p_X	cost of quasi-fixed inputs
C	short-run cost

θ	percentage difference
B	stock size
B_i	abundance of the stock of species i
q	catchability coefficient
F	production function
$A(t)$	cumulative effect of shifts in the production function over t
t	time
A^{H}	TFP adjusted for capacity utilization
A^0	conventional TFP
FC	fixed cost
VC	variable cost
LC	labor cost
f	fixed-cost function
g	variable-cost function
h	labor-cost function
grt	gross tonnage
hp	horsepower

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