THE EFFECT OF DAYS AT SEA LIMITS ON TECHNICAL EFFICIENCY

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ABSTRACT

Outputs and inputs during 1994-2006 in the USA Northeast Multispecies (groundfish) fishery—including days fished for a group of 47 otter trawl vessels fishing out of New Bedford, Massachusetts, USA—were analyzed to test the hypothesis that restricting the annual days-at-sea (DAS) of individual fishing vessels increased Technical Efficiency (TE). The results indicate that TE for the group of New Bedford trawlers increased when DAS management was introduced in 1994 and as maximum individual vessel DAS allocations were reduced over time. DAS trips were more efficient than trips for other species that did not require DAS. After DAS leasing was implemented beginning in 2004, DAS were purchased by more efficient vessels in both 2004 and 2006.

Keywords: fishery management, user rights, technical efficiency.

INTRODUCTION

The literature on open-access fishing clearly shows that use of a common property resource by economic agents maximizing profit results in producers increasing inputs until net revenue is driven to zero [1]. Firms do not produce at the technical efficiency (TE) frontier because the same amount of output could be produced with a reduction in inputs. The strictest interpretation of common property resource refers to the absence of "complete control" over fish stocks by economic agents [2]. In particular, a producer or group of producers does not hold full property rights over fish stocks, where full property rights allows the owner rights of use, (including rights to restrict others from use), the rights of sale or other options for disposal of productive assets, and the right to take yields [3]. Complete control of fish stocks in the ocean by economic agents has not proven practical. Ownership of fish stocks usually interferes with other rights, such as transportation, and fish stocks are usually not contained within an area small enough to restrict others from use. The Extended Economic Zones, claimed by the U.S. and other countries over coastal waters within 200 miles of their shores, gave countries control over fish stocks, but these fish stocks were not used for profit maximization but for political goals including production of fishery products, employment, recreation, and conservation, rather than management for net revenue. Ownership of fishing stocks by nations or other political units generally falls within public trust doctrines, usually based on maritime law and custom [4].

While economic agents rarely if ever possess complete control over marine fish stocks, user rights to apply fishing effort to fish stocks have often been granted to economic agents by government agencies. The earliest user rights granted access to fisheries in the form of vessel licenses and permits to fish for species or groups of species. The next generation of user rights applied rights to individual vessels associated with inputs, such as, number of trips or days fishing per some unit of time, or associated with outputs such as trip limits or annual or seasonal catch, generally called individual fishing quotas (IFQs) or individual transferable quotas (ITQs). Territorial user rights in fisheries (TURFS) and other community based user rights that give control over fish stocks in specific locations to groups of fishers have also been granted. User rights have also been granted to vessels to apply fishing effort in specific areas, in some cases areas that rotated, depending upon fish stocks in those areas. These user rights were often combined with other user rights. For example, the U.S. Atlantic Sea Scallop Fishery Management Plan combines licensing, with individual maximum annual days at sea (DAS), rotation between areas, various input restrictions (e.g., crew size limits), and trip limits in the regulated areas.

In theory, these user rights can improve TE if they reduce application of fishing effort to a lower rate than the open-access competitive equilibrium rate, but practice has proved this difficult [5]. In practice, user rights require other regulations to restrict fishing effort. Vessels limited by licenses increase their fishing power through larger size, more horsepower, more effective gear, and better electronics (i.e., capital stuffing). Permit owners can also transfer permits to vessels with more fishing power. Even ITQs, usually regarded as the user right closest to ownership of fish stocks, may require many other restrictions to improve TE. Copes [6] lists 14 potential problems faced by ITQ rights-based management systems, including setting total allowable catches, controlling other inputs, regulating catch of other species, and restricting fish size.

Interest in transferable user rights as mechanisms to regulate fisheries has grown throughout the world, mirroring the increase in transferable user rights for other resources, such as the cap and trade system for reducing SO_2 under the 1990 U.S. Clean Air Act and regulating CO_2 emissions in the Kyoto Accord. There is some evidence that user rights in fisheries have improved public and private benefits in these fisheries [7]. Other studies have shown economic successes for two nations that use ITQ systems for most of their commercial fisheries. In Iceland, ITQs led to a decline in the number of vessels and increases in profits, the values of quotas, and productivity of the fleet [8]. In New Zealand, the market value of transferable quotas rose, reflecting collection of resource rents [9]. There is less evidence directly linking user rights with increases in stock sizes or increases in sustainable catches.

In 1994, maximum individual vessel days at sea per year (DAS) were assigned as user rights to licensed vessels in the U. S. northeast multispecies (groundfish) fishery, a mixed species fishery. Additional restrictions were implemented on fishing effort (such as mesh size) and output controls (such as minimum fish size limits). Transfer of permits between vessels was limited by size of vessel and horsepower, and stacking of multiple permits on a vessel was not allowed. Successive regulations since 1994 reduced individual vessel DAS and increased limitations on other inputs and outputs. Beginning in 2004, leasing or exchange of DAS for the current year was allowed, with the cost of the leased DAS negotiated between the buyer and seller. According to economic theory, initial and progressive limitations on individual vessel DAS should increase the opportunity cost of a day fishing because such a day could have been used at another time. Given this increasing opportunity cost for time fished, vessel owners and their captains would be expected to chose the most productive times and places to fish, and the capital and labor inputs should used more intensely on the limited DAS. In other words, the TE (the catch per unit of capital and labor inputs for a given time fished) should increase as the opportunity cost of fishing time is increased.

OVERVIEW OF U.S. MULTISPECIES FISHERY AND MANAGEMENT

The Northeast U.S. multispecies (groundfish) fishery targets marine demersal finfish species using otter trawls, gillnets, and hook gear. The fishery primarily harvests roundfish (cod, haddock, pollock, Acadian redfish and white hake) and flatfish species (winter flounder, witch flounder, yellowtail flounder, windowpane flounder, and American plaice). These ten species are managed as 16 different stocks. Groundfish resources extend from Maine to North Carolina but most of the stocks occur in the Gulf of Maine and on Georges Bank, where management units of cod, haddock, and yellowtail flounder are shared and co-managed with Canada. Within the U.S., the New England Fishery Management Council (NEFMC or Council) has had lead responsibility for developing the groundfish management program and for making regulatory recommendations to the National Marine Fisheries Service (NMFS) under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act of 1976.

U.S. landings of multispecies groundfish totaled 146,000 mt in 1967 (Figure 1), but declined at an average annual rate of nearly 5% through 1976 to 93,000 mt (Figure 1). This decline had already been preceded by a downward trend in landings, which had begun in the 1950s.

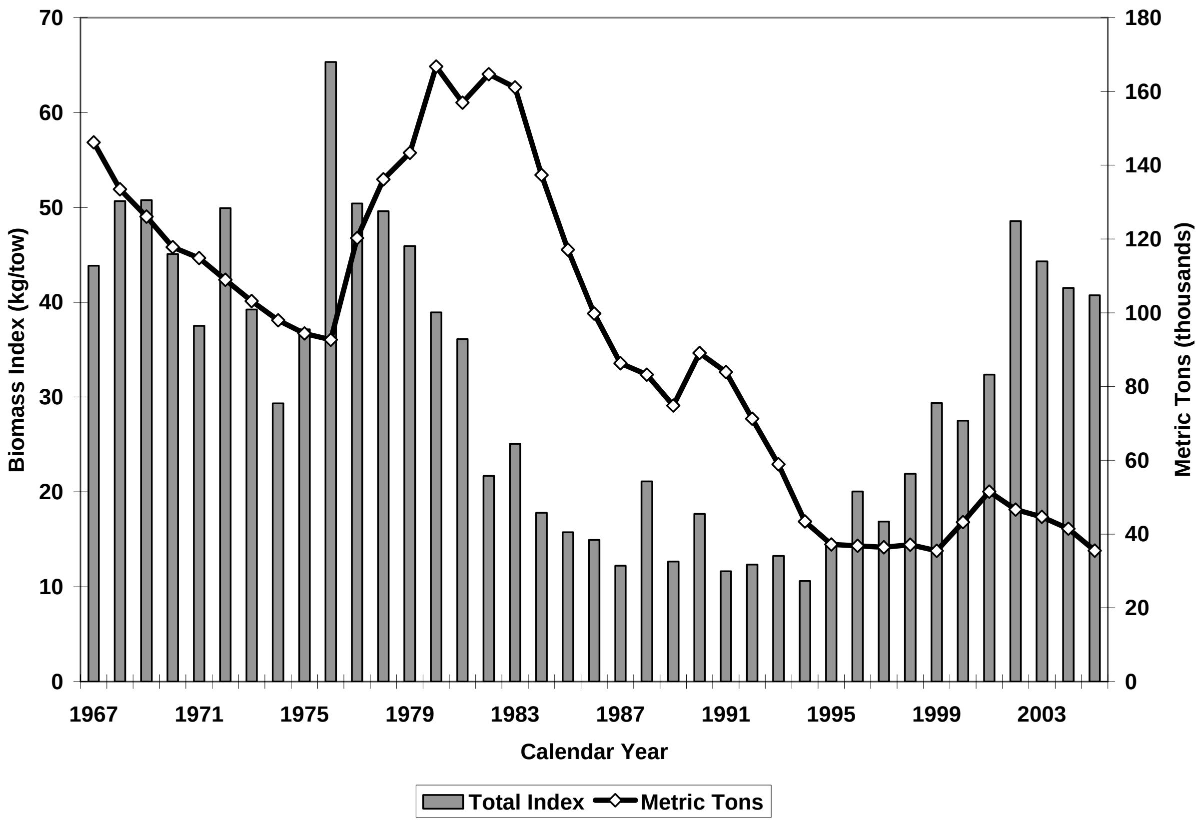

Figure 1. Landings and biomass index for 10 groundfish species in the Northeastern U.S.

With the implementation of the MSFCMA in 1977 and the exclusion of distant water fleets from the groundfish fishery, domestic landings of groundfish increased and peaked at 165,000 mt in 1982. This increase reflected a modest improvement in resource conditions (as indicated by increases in NEFSC autumn research vessel groundfish biomass indices during 1974 to 1976: see Figure 1), as well as government initiatives to "Americanize" the groundfish fishery. This economic opportunity led to the expansion of the domestic fishing fleet, which increased from 1974 to 1980 at an average annual rate of almost 9% [10]. However, the additional effort was not sustainable, and aggregate groundfish biomass began declining in 1977 followed soon thereafter by marked reductions in landings during 1983 to 1995.

During 1977-1982, the Northeast multispecies fishery was managed by stock-specific catch quotas on the stocks of cod, haddock and yellowtail flounder on Georges Bank, in the Gulf of Maine, and in Southern New England. (see Table 1 for timelines). Dissatisfied with the inevitable derby effects of quota management in an open access fishery, the Council in 1982 replaced the quota-based management system with the Interim Groundfish Fishery Management Plan (FMP). By design, the Interim FMP was subsequently replaced by a Comprehensive Groundfish FMP in 1986, which formed the basis for the FMP in effect today [11]. Both the Interim and the Comprehensive FMP relied exclusively on indirect technical control measures (such as minimum fish and mesh sizes) to constrain fishing mortality. Consequently, overfishing continued on the groundfish resource, leading to further declines in biomass and landings as described above.

Table 1. Timeline of Key Actions Affecting Groundfish Management		
Action	Date	Key Components
Magnuson Act	1976	Establishes U.S. EEZ, Fishery Management Councils
First Groundfish FMP	1977	Quota-Based management
Interim Groundfish FMP	1982	Removed quotas, establish minimum mesh and fish size
Comprehensive Groundfish FMP	1986	Established biological targets, expanded number of species
Consent Decree	1991	Settlement agreement between CLF and NMFS to develop plan to end overfishing
Amendment 5	1994	Establish limited entry, DAS system of management
Amendment 7	1996	Accelerated DAS reductions, established framework adjustment process
Magnuson-Stevens Sustainable Fisheries Act	1996	Reauthorized Magnuson Act, new requirements for biological reference points and rebuilding plans for overfished stocks
Amendment 9	1999	Established biological reference points for groundfish stocks
Report to Congress	1999	Identified several groundfish stocks as overfished triggering requirement for rebuilding plan
Law Suit (CLF and others)	2000	NMFS sued for failing to halt overfishing
Settlement Agreement	2002	Redefined DAS allocations
Amendment 13	2004	Adjusted DAS allocation, DAS leasing, sector allocation, schedule of adjustments in measures and biological evaluations
Reauthorized Magnuson-Stevens Act	2006	Requirement to end overfishing, Annual Catch Limits (ACL), Accountability Measures (AM)
Amendment 16	2009	Mid-Term adjustment to achieve rebuilding by 2014, revisions to sector allocation, framework for setting ACL and AM

In response to a lawsuit filed by the Conservation Law Foundation (CLF) in 1991, the NMFS and CLF signed a consent decree that compelled the Agency to develop a management plan to halt overfishing, Amendment 5 to the FMP was implemented in 1994 and enacted a limited entry program having DAS as a use right in the groundfish fishery, with the initial DAS allocations to be reduced at a rate of 10% per year over the next five years. However, Amendment 5 proved insufficient in achieving the stock rebuilding required under the consent decree (in part because the Amendment had taken so long to develop that stock sizes at the time were much lower than anticipated). To promote stock rebuilding, Amendment 7 was therefore implemented in 1996. Along with a number of additional measures, Amendment 7 accelerated the DAS reduction schedule adopted in Amendment 5 to 15% per year. Under Amendment 7, groundfish landings stabilized at about 36,000 mt during 1997-1999 and then increased, peaking at 51,000 mt in 2001. During these years (1997-2001), the aggregate groundfish survey biomass index increased to levels that had not been observed since the late 1970s. That is, the NEFSC autumn survey groundfish biomass index averaged 42 kg/tow during 2001-2005 compared to the 1967-1978 average of 45 kg/tow. However, almost 69% of the 2001-2005 biomass index average was due to only two of the 10 groundfish species (i.e., Acadian redfish and haddock). This is nearly twice the percentage that these two species represented in the biomass indices during 1967-1978. Omitting haddock and redfish from the average biomass indices in both time periods reveals that average aggregate biomass index during 2001-2005 for the eight remaining groundfish species (13.7 kg/tow) was less than half that during 1967-1978 (29.7 kg/tow).

Although some rebuilding of groundfish was initiated under Amendment 7, overfishing still persisted on several stocks. During the same year (1996) that Amendment 7 was implemented, the MSFCMA was reauthorized as the Sustainable Fisheries Act (SFA). The SFA added a number of new requirements to FMPs and the fishery management process, including the need to specify biological reference points for all managed stocks and to annually report to Congress on the status of these stocks. Stocks deemed to be overfished now required a rebuilding plan (which had to be implemented within one year of notification of the overfished status) to achieve a fully rebuilt condition as soon as practicable, but not to exceed ten years. In 1999, NMFS reported to Congress that several groundfish stocks were overfished and therefore required rebuilding plans. However, the New England Council had already begun the plan development process for these stocks in anticipation of receiving the formal notification from NMFS.

Despite the Council's anticipatory efforts, insufficient progress was made in completing fully developed plan for implementation within the statutory timeline specified by the SFA. Hence, the Council and NMFS implemented measures in 2000 that would continue making progress toward a rebuilding plan, but which would neither end overfishing and nor rebuild stocks within the required 10-year maximum rebuilding time horizon. In 2001, the Conservation Law Foundation again filed a lawsuit (this time along with several other environmental organizations) claiming that NMFS had failed to end overfishing on certain groundfish stocks as required by law. In 2002, a settlement agreement was reached between NMFS and all parties which, among other things, redefined DAS allocations based on new qualification criteria and compelled the Council and NMFS to complete and submit a rebuilding plan satisfactory to the Court. This rebuilding plan became Amendment 13 to the Groundfish FMP.

Amendment 13 modified the DAS qualification criteria implemented under the court-ordered settlement agreement and established three different categories of DAS: Category A DAS would be available for immediate use; Category B DAS could only be used under certain conditions (Category B); and Category C DAS could not be used (if available) until the groundfish resource had been at least fully rebuilt. Amendment 13 also allowed vessel owners to lease current year DAS to one another, and to engage in consolidation of DAS allocations through permanent DAS transfers between vessels.

DAS AS A USER RIGHT IN THE U.S. MULTISPECIES FISHERY

In 1994, direct effort control management using DAS was introduced in both the U.S. Atlantic sea scallop fishery and the Northeast multispecies (groundfish) fishery. Whereas the sea scallop FMP opted for a tiered approach in which all vessels in a category (full-time, part-time, or occasional) were allocated the same number of DAS, DAS allocations in the multispecies FMP were based on either individual vessel history or on a fleet-wide average. This was because reasonably complete fishing activity records were only available for about 170 full-time groundfish vessels. Hence, each vessel owner was given the choice of allocation at the average DAS for the 170 vessels (fleet DAS) or an individual allocation based upon a vessel's own documented fishing history (individual DAS). Nearly all vessel owners selected the fleet allocation of DAS when their documented fishing time was less than the fleet average. This process resulted in a total initial allocation of almost 250,000 DAS allocated to 1,810 vessels.

The DAS allocation to the individual DAS vessels may be thought of as a binding constraint in the firm's profit maximization problem, while the fleet DAS allocation was nonbinding, at least with the initial allocation of DAS. For example during 1994-2001, the average percentage of DAS used of those allocated was 78% for individual allocation vessels compared to 24% for the rest of the fleet. In 2002, court-ordered changes to qualification criteria for DAS allocations blurred the distinction between individual and fleet allocation vessels by aligning allocations with historical use over a more recent period. Nevertheless, DAS usage rates for vessels that formerly were individual allocation vessels remained higher (nearly 90%) than vessels allotted the fleet-wide DAS average (approximately 70%).

Groundfish DAS allocations have been reduced over time, by both a series of scheduled reductions and by separate management actions. The cumulative effect of these reductions on a vessel that fished full-time was a 72.5% reduction in allocated DAS relative to the initial qualifying baseline established in Amendment 5. To illustrate, suppose a vessel qualified for 200 DAS under Amendment 5 (see Figure 2 below). For purposes of this illustration, it is assumed that this hypothetical vessel always used its entire allocation of DAS.

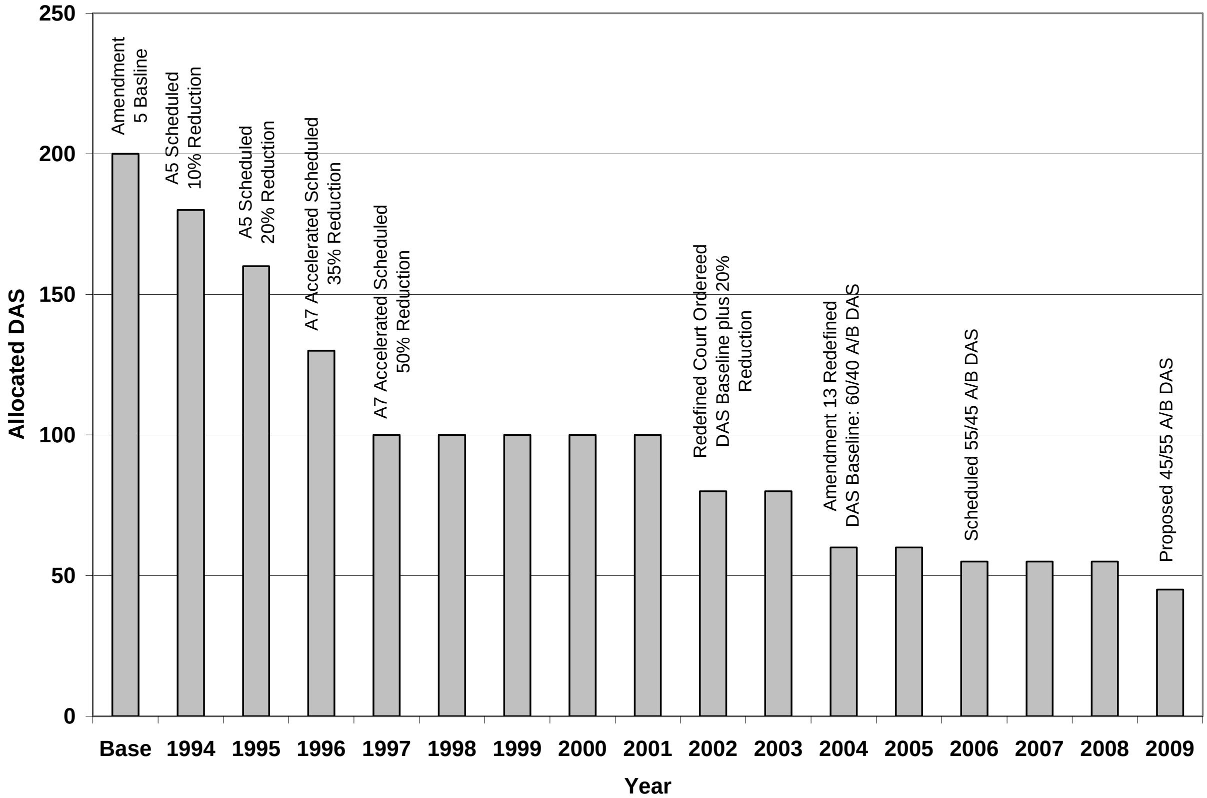

Figure 2. Timeline of management actions and reductions in allocated DAS for a hypothetical groundfish vessel.

Amendment 5 included scheduled reductions in allocated DAS of 10% per year from the baseline for five years beginning in 1994. Amendment 7 accelerated this scheduled reduction by one year such that the 50% reduction from the original baseline would be achieved in 1997, instead of 1998 as originally planned. No changes to DAS allocations were made during 1997 to 2001. The 2002 Court Order redefined baseline allocations based on prior use of allocated DAS. The Order also included a 20% reduction in allocated DAS from the redefined baseline. These allocations were maintained until Amendment 13 was implemented, which revised the court-ordered baseline and created the three different categories of DAS described above. The new baseline called an "effective effort" baseline was developed based on DAS usage during the 1996 to 2001 qualifying period, but could not exceed the allocated DAS during 2001. This effective effort baseline was then split into category A DAS and category B DAS at a rate of 60% A DAS to 40% B DAS, where the former is most comparable in terms of flexibility of use to the DAS allocations during 1994 to 2003. In the example, it is assumed that the hypothetical vessel qualified for an effective effort baseline equivalent to used/allocated DAS of 100 during the qualifying years. Amendment 13 also included a scheduled adjustment in the A/B DAS split to 55/45 during 2006 and a proposed adjustment to 45/55 in 2009. In 2007, the hypothetical vessel would have received an allocation of 55 A DAS, a reduction of 72.5% from its original baseline of 200 DAS.

METHODS

Introducing DAS as a time constraint into the firm's profit maximization for vessels that would have fished more days than allocated means that DAS had a shadow value or opportunity cost, similar to costs for other inputs. We expect that this opportunity cost increased as DAS allocations in the groundfish fishery were reduced over time, ceteris paribus.

Adding time fished to the usual production function gives us a production function $Y_i = F(T, E_i)$ where Y_i is a vector of outputs, T is time fished represented by DAS, and E_i is a vector of inputs, including crew size, vessel size, horsepower and other inputs. The vessel operator desires to maximize profit subject to the production technology and the limit of DAS. In solving this constrained maximization problem, the Lagrangean multiplier becomes the marginal cost of an additional DAS. The vessel owner will increase his usage of inputs, including DAS until the value of the marginal product for each input equals the cost of the input. As maximum allowable DAS declines, the marginal product of a DAS will increase, following the usual assumptions of production functions.

This theoretical analysis leads to two testable hypotheses: (1) TE, measured in terms of maximum obtainable output given no change in inputs, should increase with reductions in DAS and (2) time fishing, as represented by DAS, is a factor of production and therefore an asset, TE, measured as outputs per unit of inputs, should also increase with reductions in DAS.

While most of New Bedford's annual landings value derives from sea scallops, the port is also the major groundfish port in the northeastern U.S. In 1993, the year before DAS was implemented 113 offshore otter trawl vessels (commercial fishing vessels longer than 55 ft that harvested groundfish using an otter trawl) listed New Bedford as their home port. By 2005, the number of trawlers in this port had declined to 70 vessels [12]. For a panel of vessels to test our hypotheses, we selected 47 vessels that had fished from New Bedford for the period from 1994 through 2006 and had not changed ownership over the study period. The latter characteristic was important to assure that all input and output data were associated with the same vessel.

About 2/3^{rds} of the vessels in the panel selected individual DAS, with the remaining 1/3rd choosing fleet DAS. The DAS usage rate for these vessels, the percentage of DAS allocated that were actually used, increased from 76% in 1994 to 134% in 2006. Usage rates exceeded 100% after 2003 due to leasing DAS from vessels outside the panel and indicated that maximum DAS acted as a constraint on these vessels. TE was estimated using data envelopment analysis (DEA) based on landings and vessel data (including length, horsepower, and crew size) acquired during 1994 through 2006.

DEA is a mathematical programming approach for estimating and assessing TE in production [13]. It is non-parametric, and has been widely used to estimate TE of production [13]. In addition to being non-parametric and non-statistical, DEA imposes no underlying functional form on the relationship between outputs and inputs (i.e., the production function or technology). DEA is used to construct a linear, piece-wise technology relative to an ideal or best-practice frontier technology. The best-practice frontier technology is a reference technology that depicts the most technically efficient combinations of inputs and outputs. Three different DEA orientations are possible: (1) determine the minimum level of inputs required to produce a given output; (2) determine the maximum level of outputs that can be produced given existing levels of inputs; or (3) determine the maximum expansion of outputs and minimum level of inputs such that production is technically efficient.

Using the output orientation of DEA, we seek the maximum potential expansion of all outputs given that production is technically efficient. Estimates of TE are obtained by solving one linear programming problem for each and every observation. This traces out a best-practice frontier and permits TE to be estimated for each observation. The basic LP problem is as follows:

$$TE_{ocj} = \underset{\theta,z,\lambda}{Max}\,\theta \qquad \text{(Eq. 1)}$$

$$\text{subject to } \theta u_{jm} \le \sum_{j=1}^{J} z_j u_{jm},\ m = 1,\ldots,M, \qquad \text{(Eq. 2)}$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn},\ n \in X \qquad \text{(Eq. 3)}$$

$$\sum_j z_j = 1.0 \qquad \text{(Eq. 4)}$$

$$z_j \ge 0,\ j = 1,2,\ldots,J \qquad \text{(Eq. 5)}$$

where θ is a measure of TE, ($\theta \ge 1.0$); X is a vector of factors of production; z_j is a vector of intensity variables used to construct the piece-wise technology, and u_{jm} is a vector of outputs. If we multiply the observed output by θ, we obtain an estimate of the technically efficient output. We impose strong disposability in outputs and variable returns to scale through our inequality constraint on outputs and our equality constraint on the intensity variables.

We also examined data on leasing DAS (selling and buying use of DAS for that fishing year) between vessels with multispecies permits as evidence that DAS were an asset, derived from their value as an input into the production process. Data on leasing, including the number of DAS bought and sold by year for each vessel in the panel, and the total value paid per year for each vessel was also supplied by the NEFSC.

FINDINGS

To test the hypothesis that opportunity costs resulting from DAS management increased TE, TE scores were computed for the annual production of all species by vessel, as well as for trip-level production on DAS trips and trips that did not use DAS. TE is measured relative to 1.0, so that scores greater than 1.0 are indicative of lower levels of TE. Mean annual TE scores show an increasing TE trend from 1994 through 2001 (Table 2). Mean TE was relatively stable through 2005, but declined significantly in 2006.

Annual production comprises landings from (a) trips where DAS were required to be used when harvesting groundfish and (b) trips which did not harvest groundfish and were not constrained by DAS. Mean TE scores for DAS trips were significantly lower than the mean TE scores on non-DAS trips (Table 2). This difference in TE between trips with a higher opportunity cost of time and trips where fishing time was not constrained by maximum DAS rights may explain the relatively low TE score in 2006. That is, another factor reducing TE was operational. In 2006, a scheduled management action developed by the NEFMC was delayed. resulting in an emergency action taken by the NMFS. This action implemented most of the Council recommendations but differed in one important respect. The Council plan called for differential DAS counting at a rate of 2:1 in a designated portion of the Gulf of Maine and at a rate of 1:1 in all other areas. The NMFS emergency action implemented differential DAS counting at a rate of 1.4:1 in nearly all areas. The NMFS action was not replaced by the Council plan until late November 2006, nearly seven months into the fishing year (which annually begins on 1 May).

Table 2. Mean Technical Efficiency (TE) Scores for Annual and Trip-Level Data

Year	Mean Annual TE Scores	Mean TE Scores on DAS Trips	Mean TE Scores on Non-DAS Trips
1994	1.69	5.85	14.27
1995	1.65	6.37	19.66
1996	1.32	5.36	14.85
1997	1.17	5.21	13.78
1998	1.19	4.36	12.79
1999	1.23	5.82	15.07
2000	1.11	5.65	17.15
2001	1.04	3.84	18.24
2002	1.25	4.11	18.18
2003	1.08	3.80	11.83
2004	1.06	4.41	12.12
2005	1.18	8.26	79.54
2006	1.59	6.59	118.72

For the New Bedford trawler fleet which typically does not fish in the Gulf of Maine, this implementation schedule meant that the opportunity cost of time was higher during the first seven months of the fishing year than it would have been had the Council's plan been implemented on time. Knowing that the emergency action would eventually be replaced by the Council's plan, the vessels within the 47 New Bedford trawler group may have saved their DAS for later in the year when the opportunity cost of time would be lower and in the interim substituted non-DAS trips for DAS trips. To assess this inference, the cumulative share of DAS trips accomplished from May to November of 2006 was compared to the cumulative share of DAS trips taken in 2005 and in 2007, where the latter two years correspond to periods where the opportunity cost of time were unaffected by differential DAS counting.

The results suggest that during 2006 the New Bedford panel took proportionally fewer DAS trips and conversely, proportionally more non-DAS trips from May through November than they did in either 2005 or 2007 (Figure 3). That is, the cumulative distribution of DAS trips in 2006 lies to the right of the cumulative DAS distributions in 2005 and 2007 indicative of a temporal delay in DAS trip taking in 2006 and a presumed increase in the proportion of non-DAS trips. Since non-DAS trips have significantly lower TE, the probable larger proportion of non-DAS trips in 2006 would have generated a lower annual TE score than in previous years. If this is the case, then annual TE in 2007 would be expected to be higher than in 2006, a test that can be performed once complete fishing year 2007 data are available.

Prices for leased or use of DAS for the current year indicate that DAS were inputs in the production process and if transferable, were a fungible asset. Since leasing began in 2004, New Bedford trawler owners have been net purchasers of DAS through the leasing program that started with Amendment 13. The total number of DAS purchased by the panel of New Bedford draggers increased from 662 in 2004 to 1281 in 2005 to 1362 in 2006. The average price for a DAS for these vessels dropped from $988 in 2004 to $704 in 2005 to $666 in 2006. As with the price of any asset, prices for DAS depend upon supply and demand in the market. There is little doubt that the supply of DAS, the source of supply for leased DAS, dropped as previously shown in Figure 2. Demand may also have declined due to decreasing revenues per day of fishing and increasing costs. The New Bedford vessels in our study also tended to engage in the leasing market progressively later in the fishing year perhaps taking advantage of lower leasing prices since lease prices tended to decline as the fishing year progressed.

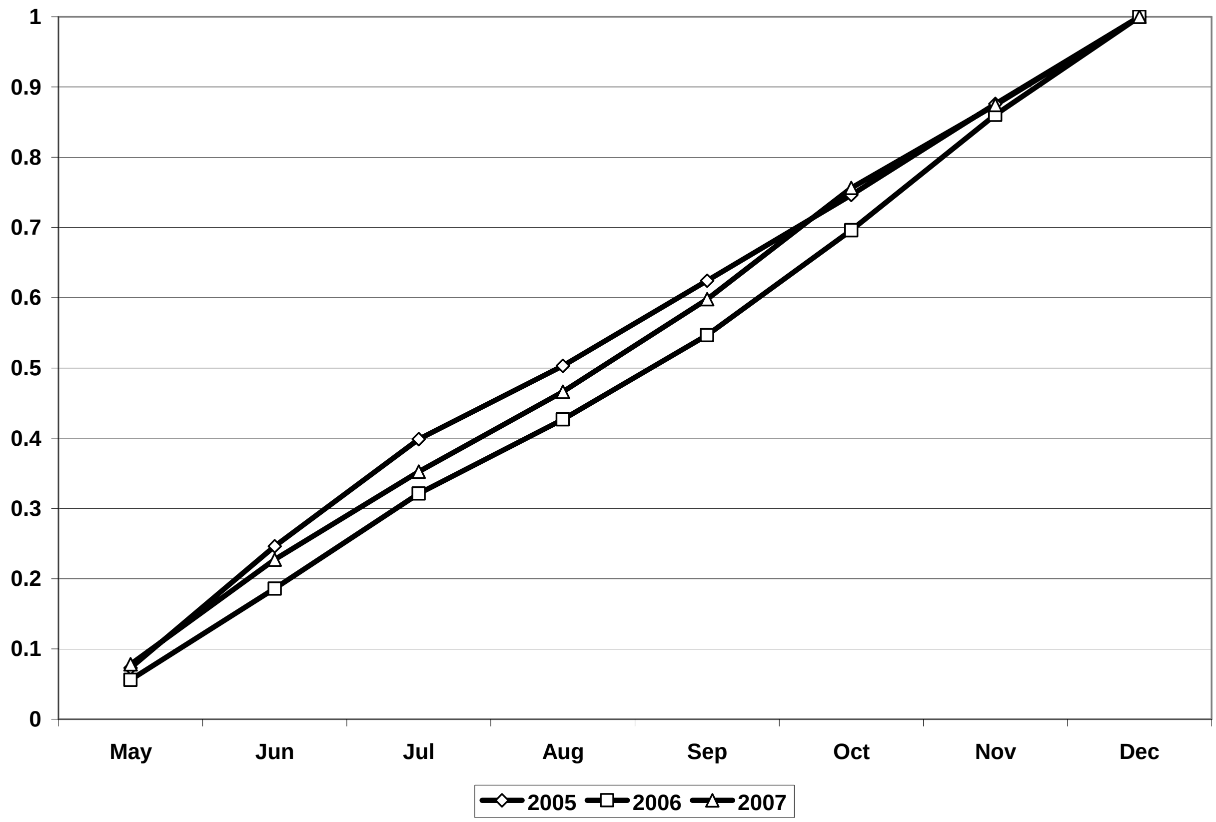

Figure 3. Cumulative share of DAS trips taken from May to November for 2005, 2006, and 2007

Indications exist that the average of recorded prices for leasing DAS is a biased estimate of the true average. Recorded prices include transactions of DAS between vessels that have the same owner. Owners lease DAS between their own vessels because permanent transfers of DAS between vessels would involve the loss of some fishing permits and a conservation tax would be applied to the transferred DAS. Although leasing transactions that reported no value were eliminated from any of the analyses that were conducted, some of the recorded values may have been internal accounting value rather than a market exchange value. The coefficient of variation for leasing prices, especially in 2004 (48%), also suggests an inefficient market or misreported prices. By comparison, the coefficient of variation in an internet search of prices for a Samsung HDTV in 2005 was 20% [14].

When costs are applied to the use of a common property resource, economic theory predicts that firms will either (a) increase output per unit of the resource, or (b) more technically efficient firms will outbid less technically efficient firms for the resource because they produce more output per unit of the resource. In other words, the cost of the resource per unit of output will decline. Keohane has shown that the cap and trade system that allocates SO_2 reduced costs for eliminating SO_2 with scrubbers by 17-20% compared with performance standards reducing the same amount of SO_2 emissions [15].

To test the hypothesis that leasing increased TE, average DEA scores during 2004-2006 were compared between those vessels in the New Bedford trawler group which bought DAS and those that did not. Based on the DEA scores, the vessels which purchased DAS vessels were more efficient than those which did not, but these differences were not significant (at the 10% level using a Kruskall-Wallis test) in 2005

(Table 3). However, all of the comparisons may have been affected by the low number of the 47 vessels which did not buy DAS, especially in 2005 (18 of the 47 vessels) and 2006 (15 of the 47 vessels).

Table 3. Mean Technical Efficiency (TE) Scores for Vessels that Leased and did not Lease DAS.

Year	Efficiency Scores For Leased DAS	Efficiency Scores for Non-Leased DAS	Efficiency Scores for Vessels that Bought DAS	Efficiency Scores for Vessels that did not Buy DAS
2004	2.11	28.93	1.02	1.08
2005	29.20	1.88	1.29	2.22
2006	2.02	1.67	1.10	1.32

The average TE of fishing trips using leased DAS was also compared with the average TE of fishing trips using allocated DAS, based on the hypothesis that captain and crew would work harder on trips with leased DAS because they had paid an extra fee for the leased DAS. In the New Bedford offshore trawler fleet, vessels pay for leasing costs and other trip costs (such as fuel) from either (a) the gross stock before the split between owner and crew; or (b) from the crew share [12]. The evidence is mixed that TE is higher for trips using leased DAS (Table 3). That is, technical efficiency was higher on leased DAS in 2004 but lower in 2005 and 2006 (although the mean TE scores in 2006 were not statistically different). An alternative hypothesis is that the leasing cost is perceived to be less than the opportunity cost of an allocated DAS, which would weaken the argument that captain and crew would work harder on leased DAS trips.

POLICY IMPLICATIONS

DAS should be considered a low quality property or user right; as quantities of DAS were not guaranteed even during the fishing year and often changed. Furthermore, the value of DAS was weakened by regulations that either limited output or increased costs or both. DAS user rights have also been a weak management instrument. Capping total DAS did not easily transfer to a target yield or biomass because of latent effort caused by over-allocation of DAS and the DAS limits that may have been commensurate with conservation objectives were not acceptable. Instead, indirect limits on other inputs and outputs were substituted for DAS limits. Even with an assortment of regulations to bolster DAS limits, fishery managers were not able to reach their goals. DAS regulations may also have discouraged technological change because improvements in technology probably encouraged fishery managers to reduce DAS allocations. Further, DAS controls do not provide incentives to use or invest in more selective gear. Aside from the Northeast U.S. scallop and groundfish fisheries, DAS have only been used as a management tool in the Scottish mixed trawl fishery, and the experience there has been similar to the experience in the U.S. [16].

These problems with DAS regulations notwithstanding, an increase in TE increase was detected for the group of 47 otter trawl vessels fishing out of New Bedford, Massachusetts, USA subsequent to the enactment of maximum individual annual DAS limits. DAS trips for these vessels were also more efficient than for trips for non-groundfish species that did not require DAS

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