Assessing Efficiency Gains from Individual Transferable Quotas: An Application to the Mid-Atlantic Surf Clam and Ocean Quahog Fishery

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Delayed fishing fleet restructuring complicates the assessment of efficiency gains from individual transferable quota (ITQ) fisheries management programs. This article presents a methodology to estimate harvest sector efficiency gains in lieu of incomplete fleet restructuring. The methodology is applied to assess the efficiency gains in the Mid-Atlantic surf clam and ocean quahog fishery ITQ program. While roughly 128 vessels harvested clams under the previous management regime, the analysis suggests that 21–25 vessels will remain under ITQs. The efficiency gains are estimated to be between \$11.1 million and \$12.8 million annually (1990 dollars).

Key words: efficiency gains, fleet restructuring, individual transferable quotas.

An important benefit of individual transferable quota (ITQ) fisheries management programs is the efficiency gains that may emerge under enhanced property rights. Quota rights provide a mechanism to eliminate redundant capital that may have accumulated under the pre-ITQ management regime and encourage cost-efficient production once industry restructuring is complete. Benefits emerge as retired capital is employed in other more productive uses, and as remaining fishers exploit production economies under the ITQ operating rules. For example, the elimination of input controls and harvest time restrictions can improve (input) allocative efficiency and vessel capacity utilization on fishing vessels that remain active under the ITQ management regime.

In initially overcapitalized fisheries, industry restructuring will be a key determinant of the total efficiency benefits that emerge under the ITQ program. Because restructuring can take time, possibly years, to complete, ITQ program benefits emerge over the longer term. Nonetheless, the appropriate benchmark for assessing the performance of ITQ programs is the efficiency gains that are generated after all economies are realized. Benefits generated during the restructuring phase can underestimate the full program benefits and can bias against ITQ management reform. Moreover, the transition phase benefits are arbitrary because they depend on the extent to which restructuring is complete or the extent to which all economies available under the ITQ program have been captured.

This article presents a methodology to analyze harvest sector efficiency gains from ITQ management reform in the presence of incomplete fleet restructuring. The approach is to exploit the economic incentives implicit in the ITQ system to predict the fleet structure and individual vessel output levels expected to prevail under ITQs. The anticipated efficiency gains in the harvest sector are then estimated from the predicted fleet structure. Specifically, harvest sector efficiency gains are calculated as the reduction in total harvesting costs expected under the ITQ-regime fleet structure. The methodology is applied to the Mid-Atlantic surf clam and ocean quahog fishery (hereafter, the MA clam fishery), which switched from limited entry (LE) management to ITQs in October 1990. During the LE regime (1977–90) roughly 128 fishing vessels actively harvested surf clams and ocean qua-

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hogs. Many of these vessels operated well below an efficient scale of production due to the stringent harvest time restrictions that were imposed under LE. The analysis in this article reveals that the ITQ-regime fleet will consist of 21–25 vessels operating at a cost-efficient output scale. Hence, the elimination of redundant harvesting capital and the realization of scale economies is an important source of efficiency gain in the MA clam fishery.

A second source of efficiency gain in the MA clam fishery is associated with returns to specialization or single-species production. Strict surf clam harvest time restrictions under the LE-regime induced fishers to diversify into the production of ocean quahogs to take advantage of otherwise idled vessel capital (Strand, Kirkley, and McConnell; Lipton and Strand). The analysis of this article suggests that the clam harvesting technology exhibits scope diseconomies (cost anti-complementarities) under the ITQ-regime operating rules. As a consequence, clam fishers should eventually return to specialized production (single clam species) under the ITQ program, resulting in additional efficiency gains.

The total fleet harvesting cost incurred under LE is estimated to be \$28.4 million in 1990. All values are reported in 1990 dollars. Total cost incurred to harvest the same total allowable catch (TAC) under ITQs, conditional on the predicted ITQ-regime fleet structure, is estimated to be \$15.6 million annually. Harvest sector efficiency gains in the range of \$12.8 million annually are thus possible under the ITQ management program.

The analysis of the MA clam fishery underscores the importance of controlling for long-run fleet adjustments when assessing the performance of ITQ programs. Roughly fifty vessels remained active in the MA clam fishery at the end of 1994, four years after the ITQ program was introduced. Of these fifty vessels, many continued to operate below cost efficient output levels, and fourteen vessels continued to harvest multiple clam species. Evidence suggests that the 1994 fleet was still in a transition phase and 25–29 vessels would eventually exit the fishery. Vessels that remained would adjust quota holdings to facilitate single-species production. Total harvest cost incurred by the 1994 fleet is estimated to be \$19.9 million. Accordingly, the efficiency gain estimates based on the 1994 fleet structure would underestimate the post-transition phase gains by \$5.8 million annually.

The following section presents a model of equilibrium fleet structure under an ITQ program. Then we briefly review the regulatory history and industry background in the MA clam fishery. The analysis of the harvest cost technology that is used to identify the ITQ-regime fleet structure is then presented, followed by estimates of harvest sector efficiency gains. The final section summarizes the main results and discusses implications for future assessment of ITQ programs.

Model of Equilibrium Fleet Structure in the ITQ Fishery

It is well known that ITQs provide economic incentives that promote efficient resource use (Montgomery). The reason is that the residual return to quota ownership, or quota rent, is maximized on a cost-efficient harvesting operation. Transferability implies that quota will eventually gravitate into the hands of those who are able to generate the largest residual return from ownership. Any quota owner that earns less than the maximal rent can be made better off by trading the quota asset (Weninger and Just). This incentive structure leads to an equilibrium quota distribution and fleet structure.

Consider a fishery that generates a surplus harvest of two fish species in each period. Assume that the resource manager distributes quota in an amount that corresponds to the desired TAC of each species.[1] Let Q_i, $i = 1$, 2 denote the TAC and total available quota for species i. The ITQ regulation requires that fishers own or lease quota in an amount that corresponds to their output level; thus, output and quota will be used synonymously. To facilitate the identification of the ITQ-regime fleet structure, the unit of analysis will be an individual (representative) vessel operation.[2]

Assume that all fishers have access to the same harvest technology. Denote the cost function for a single-product vessel as $C(q_i, v, S_i)$, $i = 1, 2$, where q_i is the quantity of output i, $\mathbf{v}$ is a vector of strictly positive factor input prices and S_i is an index for the ith fish stock. A "tilde" is used to distinguish mul-

[1] See Clark for an analysis of the social rent maximizing TAC in a multispecies fishery.

[2] The focus on a representative vessel operation is simplistic but facilitates presentation of the basic intuition. The section "ITQ Regime Fleet Structure and Returns to ITQ Management Reform" briefly discusses implications of heterogeneity in the ITQ-regime fleet structure.

tioutput harvest operations. Let $\tilde{C}(\tilde{\mathbf{q}}, v, S)$ denote the multiproduct cost function, where $\tilde{\mathbf{q}} = (\tilde{q}_1, \tilde{q}_2), \tilde{q}_i > 0, i = 1, 2$, is the output vector and $\mathbf{S} = (S_1, S_2)$ is the vector of stock indices. Assume that the single- and multioutput cost functions are twice differentiable, increasing and convex over a bounded output space, increasing and concave in $\mathbf{v}$, and nonincreasing in $\mathbf{S}$. Hereafter $\mathbf{S}$ and the TAC for each product are assumed constant.

In a multiple output fishery, three possible fleet structures must be considered. First, individual vessel operations may harvest a single output leading to a specialized fleet structure. Second, all vessels may produce multiple outputs in which case the fleet will be fully diversified. Finally, MacDonald and Slavinsky identify a mixed-product market structure under which multiproduct (diversified) and single product (specialized) firms operate simultaneously. Similar conditions apply in a multiproduct ITQ fishery leading to a third, mixed ITQ-regime fleet structure comprised of both single- and multioutput operations. Conditions under which a specialized, diversified and mixed fleet structure will emerge under ITQs are discussed in the following sections.

Specialized Fleet Structure

Under single-output production, the residual return to the marginal unit of output is the difference between the output price and the marginal harvest cost:

$$(1) \quad p_i - \frac{\partial}{\partial q_i}\{C(q_i, v, S_i)\}, \qquad i = 1, 2$$

where p_i is the ex-vessel price for output i. The residual return in equation (1) attains a maximum at the average cost-minimizing output level given by

$$(2) \quad q_i^* = \arg\min_{q_i \leq \ddot{q}_i} \left\{\frac{C(q_i, v, S_i)}{q_i}\right\}, \qquad i = 1, 2$$

where $\ddot{q}_i$ is the upper bound for output space i.

In the presence of a well-functioning ITQ trading market, a quota lease rate, L_i, will emerge in the fishery. Any single-product operator who cannot match the fully efficient technology or production plan will earn a residual return that is less than the market lease rate and is better off trading the ITQ asset (Weninger and Just). In the ITQ equilibrium, specialized operators will harvest q_i^* units and earn the maximal per unit (per period) return, $L_i^* = p_i - [C(q_i^*, v, S_i)/q_i^*]$.

The number of operations comprising the specialized ITQ-regime fleet is determined by

$$(3) \quad N_i^* q_i^* \approx Q_i, \quad i = 1, 2$$

where N_i^* denotes the number of vessels harvesting species i. Note that Q_i/q_i^* may not be an integer and thus equation (3) will hold only approximately ($\approx$). The number of single-species vessels that prevail will be an integer that lies closest below or above Q_i/q_i^*. In equilibrium, N_i^* is expected to equal the integer at which the corresponding per vessel harvest level, Q_i/N_i^*, attains the lowest average harvest cost, and thus the largest residual return to quota ownership. When Q_i/q_i^* is large, the difference between Q_i/N_i^* and q_i^* will be small.

Observe that if $N_i^* - 1$ fishers are active, they must produce in excess of q_i^* and, by definition, earn a residual return less than L_i^*. A fisher could bid sufficient quota away from the $N_i^* - 1$ active fishers and profitably enter the fishery. Alternatively, if $N_i^* - 1$ fishers are active, the corresponding per vessel output must be less than q_i^*, and the residual return to the quota asset would be less than L_i^*. An active fisher would find it profitable to sell their quota allocation and exit the fishery.

The total cost of harvesting the TAC under the specialized fleet structure, denoted TC_S, will be

$$(4) \quad TC_s = \sum_{i=1}^{2} N_i^* C(q_i^*, v, S_i).$$

Multiproduct Fleet Structure

Multiproduct operations are viable if the residual return to the ITQ asset(s) under multioutput production exceeds or is at least equal to the residual earned by a specialized operator. This will be the case only if the harvest technology exhibits economies of joint production or economies of scope. A sufficient condition for scope economies is cost complementarity among outputs (Baumol, Panzar, and Willig).[3] Cost complementarity implies that the marginal cost of harvesting output i is reduced if the operator also harvests output j $(i \neq j)$.

Multiproduct cost concepts can be used to identify the output bundle that generates the greatest return to the quota asset(s). Let $\tilde{\mathbf{q}}^*$ denote a reference output vector that minimizes the multiproduct ray average cost (RAC). The vector $\tilde{\mathbf{q}}^*$ fully exhausts all cost advantages from adjusting the scale of production as well as the product mix. Formally,

$$\tilde{\mathbf{q}}^* = (\tilde{q}_1^*, \tilde{q}_2^*) = \arg\min_{\tilde{q} \le \ddot{q}, \alpha} \left\{ \frac{\tilde{C}(\tilde{\mathbf{q}}, v, S)}{\alpha \cdot \tilde{\mathbf{q}}} \right\},$$

where $\ddot{\mathbf{q}}$ is the upper bound for the multiproduct output space, and $\boldsymbol{\alpha}$ is a proportional weight vector (Panzar). The equilibrium quota lease rate evaluated at $\tilde{\mathbf{q}}^*$ is

$$(5) \quad \tilde{L}_i^* = p_i - \frac{\partial}{\partial \tilde{q}_i}\{C(\tilde{\mathbf{q}}^*, v, S)\}, \qquad i = 1, 2.$$

Under the cost complementarity assumption, a specialized operator will be unable to profitably bid quota away from a diversified operator because the residual earning will be less than $\tilde{L}_i^*$. If all fishers produce $\tilde{\mathbf{q}}^*$, and the TAC of each species is exactly harvested, the equilibrium number of vessel operations, $\tilde{N}^*$, will be determined by

$$(6) \quad \tilde{N}^*\tilde{\mathbf{q}}^* \approx Q.$$

The integer problem applies in the diversified fleet. The actual number of vessels in the ITQ-regime fleet will be determined by similar logic as in the specialized fleet case. The total cost under the fully diversified fleet structure, TC_D, is

$$(7) \quad TC_D = \tilde{N}^*\tilde{C}(\tilde{\mathbf{q}}^*, v, S).$$

Mixed Production Fleet Structure

The conditions under which the ITQ regime fleet is fully diversified are somewhat unique. In particular, $\tilde{q}_1^*/\tilde{q}_2^*$ must coincide with the ratio of TAC quantities Q_1/Q_2 set by the management authority. A more likely scenario is that $Q_1/Q_2 \neq \tilde{q}_1^*/\tilde{q}_2^*$, in which case the ITQ regime fleet may be mixed.

For concreteness, suppose the ratio of Q_1/Q_2 is greater than $\tilde{q}_1^*/\tilde{q}_2^*$. The analysis of Q_1/Q_2 less than $\tilde{q}_1^*/\tilde{q}_2^*$ follows symmetrically. A fully diversified fleet cannot maintain the output mix implied by $\tilde{\mathbf{q}}^*$, and simultaneously harvest the entire Q_1. With surplus Q_1, the value of species 1 quota will fall providing the opportunity for a specialized operator to enter the fishery. The resulting quota distribution and fleet composition will depend on the nature of the cost complementarity. First, if the lease rate for species 1 quota is low, diversified operators will expand production of $\tilde{q}_1$ in order to maximize their profit. Let $\tilde{\mathbf{q}}^\circ$ denote an output vector that is proportional to Q_1/Q_2, and maximizes the residual return for each output:

$$(8) \quad \tilde{\mathbf{q}}^\circ = \arg\max_{\tilde{q} \le \ddot{q}} \left\{ \tilde{L}_i^\circ = p_i - \frac{\partial}{\partial \tilde{q}_i}\tilde{C}(\tilde{\mathbf{q}}, v, S) \right\}$$
$$\text{s.t. } \tilde{q}_1^\circ/\tilde{q}_2^\circ = Q_1/Q_2, \qquad i = 1, 2.$$

If the residual return defined in equation (8) exceeds the residual earned on a specialized operation, as defined in equation (2), then the ITQ-regime fleet structure will remain fully diversified. The situation is one where the economies of scope are large so that the marginal harvesting cost on a diversified operation is less than the marginal harvesting cost for single-product operators. The residual return at $\tilde{q}_1^\circ$ remains above a specialized operator's maximum offer price, and specialized operators cannot profitably enter the fishery. In this case, the number of vessels is given by $\tilde{N}^\circ\tilde{\mathbf{q}}^\circ \approx Q$ and fleet costs are $\tilde{N}^\circ\tilde{C}(\tilde{\mathbf{q}}^\circ, v, S)$.

If the scope economies are less pronounced, or if Q_1/Q_2 is significantly larger than $\tilde{q}_1^\circ/\tilde{q}_2^\circ$, then $\tilde{L}_1^\circ$ will fall below the residual earned under specialized production, and the ITQ-regime fleet will be mixed. Recall that in equilibrium all gains from quota trading must be exhausted. In a mixed fleet, single- and multiple-output producers will adjust their species 1 quota to satisfy

$$(9) \quad \left[p_1 - \frac{\partial}{\partial \tilde{q}_1}\tilde{C}(\tilde{\mathbf{q}}^*, v, S)\right] = \left[p_1 - \frac{\partial}{\partial q_1}C(q_1^*, v, S_1)\right].$$

[3] Scope economies can arise from product-specific fixed costs (Gorman). The analysis here focuses on scope economies that arise from cost complementarity.

With $\tilde{q}_1^*$ satisfying equation (9), diversified operators will adjust $\tilde{q}_2$ to satisfy

$$(10)\quad \tilde{q}_2^* = \arg\max_{\tilde{q}_2 \leq \ddot{q}_2} \left\{ p_2 - \frac{\partial}{\partial \tilde{q}_2} \tilde{C}(\tilde{q}_1^*, v, S) \right\}.$$

The equilibrium lease rates under the mixed fleet structure are given by

$$\tilde{L}_1^* = \left[p_1 - \frac{\partial}{\partial \tilde{q}_1} \tilde{C}(\tilde{\mathbf{q}}^*, v, S) \right] = \left[p_1 - \frac{\partial}{\partial q_1} C(q_1^*, v, S_1) \right]$$

for species 1 quota and

$$\tilde{L}_2^* = \left[p_2 - \frac{\partial}{\partial \tilde{q}_2} \tilde{C}(\tilde{\mathbf{q}}^*, v, S) \right]$$

for species 2 quota. The number of multioutput operations in the mixed fleet is determined by

$$(11)\quad \tilde{N}^* \approx Q_2/\tilde{q}_2^*$$

and the number of single-product operations in the mixed fleet is determined by[4]

$$(12)\quad N_1^* \approx (Q_1 - \tilde{N}^* \tilde{q}_1^*)/q_1^*, \quad N_2^* = 0.$$

Finally, the total harvesting cost under a mixed fleet, TC_M, is given by

$$(13)\quad TC_M = \tilde{N}^* \tilde{C}(\tilde{\mathbf{q}}^*, v, S) + N_1^* C(q_1^*, v, S_1).$$

Harvest sector rents under the ITQs are the total revenues generated from the TAC, less the minimum of equations (4), (7), and (13);

$$(14)\quad \sum_{i=1}^{2} p_i Q_i - \min\{TC_S, TC_D, TC_M\}.$$

It follows that the harvest cost technology must be investigated to determine cost-efficient output levels and product mixes. The ITQ-regime fleet structure and harvest sector rents in equation (14) may then be compared to pre-ITQ harvesting costs to obtain an estimate of the anticipated efficiency gains. The remainder of the article discusses the application of this methodology to the MA clam fishery.

Industry Background

This section discusses features of the regulatory history and industry background that influence the subsequent empirical analysis. Additional information may be obtained from the Mid-Atlantic Fisheries Management Council 1988, 1996; Lipton and Strand; McCay and Creed; Strand, Kirkley, and McConnell; and Wang.

Regulatory History

The Mid-Atlantic Surf Clam and Ocean Quahog Fisheries Management Plan (FMP) was approved in November 1977. Limited entry permits were issued to 184 surf clam and/or ocean quahog vessels, and an entry moratorium was imposed. Vessel replacement for surf clam permit holders was prohibited unless the vessel left the fishery involuntarily (e.g., sinking or fire). The FMP set quarterly quotas for surf clams and ocean quahogs. To maintain quarterly quotas, limits were placed on the days that fishing was allowed and on the total hours of fishing per week. During the LE regime, increasingly stringent harvest time restrictions were placed on surf clam fishers even though quarterly quotas did not dramatically change throughout the period. In response to severe harvest time restrictions, some vessels expanded ocean quahog production to take advantage of otherwise idle vessel capital (Strand, Kirkley, and McConnell).

Amendment #8 to the FMP was adopted on 25 October 1989, and was approved by the National Marine Fisheries Service (NMFS) on 23 March 1990. The amendment changed the management system to ITQs on October 1, 1990. An initial distribution of species-specific quota rights was distributed gratis to 161 vessel owners: 154 received surf clam quota and 117 received ocean quahog quota. The number of initial allocations exceeded the number of active vessels because some vessels received quota for both clam species. Quota was delineated as percentage shares of the TAC, based on a formula of historical

[4] The mixed fleet structure will include diversified vessels and specialized vessels of both types only if species 2 specialists earn exactly the same return as a diversified operator at $\tilde{\mathbf{q}}^*$.

catch rates (80%) and vessel size (20%). All harvest time restrictions were lifted under ITQs.

Empirical Considerations

Surf clams and ocean quahogs are harvested with hydraulic dredges towed by the vessel. Clam fishers travel from port to a chosen site and dredge the sea bottom. Most trips are completed in a single day, although two-day ocean quahog trips occur. Fishers may return to a lucrative site until its yield declines, at which point the fisher may search for an alternate site. Catch uncertainty is small relative to other fisheries and will be ignored.

Surf clams and ocean quahogs are sold directly to processing firms that conduct value-adding activities before selling the final consumable product in downstream markets. The perishable nature of the clams, scheduling of processing activities, and the need to coordinate with downstream buyers requires tight vertical coordination between fishers and processors. Processors may place orders with a vessel captain weeks in advance of actual harvest (Wallace, personal communication). Fishers are assumed to minimize the cost of delivering the surf clam and ocean quahog orders placed by processors, subject to exogenous prices, technology, and clam stock levels.

Multispecies clam fishing from the same vessel is feasible. Ocean quahogs are smaller and require adjusting the dredge knife spacing and the angle at which the dredge is set relative to surf clams (almost flat for ocean quahogs to approximately two degrees for surf clams). Ocean quahogs are located farther from shore, and quahog fishing is subject to more severe weather conditions. Slightly larger vessels and additional crew may be preferred on quahog trips. Larger vessels miss fewer days at sea because of poor weather, and the extra crew facilitates the dredging operation during bad weather.

The number of clam cages that can be carried on the vessel and the number of trips per calendar period impose a short-run constraint on total harvest capacity. Fishing trips involve one to two days at sea, plus off-loading and replenishment of fuel and supplies. Harvest costs may rise sharply (become infinite) beyond a particular harvest capacity. Logbook data sources and industry participants were consulted to determine the maximum harvest capacity for each clam species under a variety of vessel size classes as measured by the vessel gross registered tonnage (GRT).

Empirical Specification and Estimation of the Harvest Cost Technology

Harvesting costs are separated into fixed and variable costs within each three-month or quarterly production period. Within each quarter, the maximum flow of vessel capital services is treated as a fixed operating variable. The GRT of the fishing vessel is used as a proxy for the flow of vessel capital services available for production.

Discussions with industry participants indicate that the number of crew on board is rarely adjusted; labor services are used in proportion to the flow of vessel services. Furthermore, if the crew is paid under a revenue share system, labor costs are analogous to an ad valorem tax on revenue. In this setting, it is not clear that the labor input is adjusted at its cost margin. For these reasons, the flow of labor services used in harvesting activities is approximated by the GRT variable.[5]

Variable inputs include (*i*) fuel, engine oil, and lubricants; and (*ii*) gear, supplies, and repairs (hereafter the "gear" input). The gear input includes food consumed by the captain and crew, and maintenance costs for the clam dredge. Dredge maintenance is the largest component of the gear input cost (Wallace, personal communication). Denote the variable harvest cost function as

$$(15) \quad c(v_1, v_2, q_1, q_2 \mid z, S_1, S_2)$$

where v_1 and v_2 are the respective prices of fuel and gear, q_1 and q_2 are the respective quantities of surf clams and ocean quahogs, z is the vessel GRT, and S_1 and S_2 are, respectively, surf clam and ocean quahog stock indices. Denote the vector of arguments in $c(\cdot)$ as $\mathbf{Z} = (v_1, v_2, q_1, q_2, z, S_1, S_2)$ with individual element Z_j, j = 1, . . . , 7. The translog variable cost function is specified for $c(\cdot)$:

[5] The GRT variable will overestimate the actual vessel and labor services that are used in production when the vessel harvest capacity is not fully utilized. Previous studies have attempted to control for this problem by including days-at-sea in developing the proxy for capital services (Squires). The product of trips-taken and GRT was highly collinear with the remaining endogenous variables in the model and could not be used as an indicator of capital and labor.

$$(16)\quad \ln c(\mathbf{Z}, \boldsymbol{\Gamma}) = a_0 + \sum_{j=1}^{7} a_j \ln Z_j + \frac{1}{2}\sum_{j=1}^{7}\sum_{k=1}^{7} b_{jk} \ln Z_j \ln Z_k$$

where $b_{jk} = b_{kj}$ for $j, k = 1, \ldots, 7$, and $\boldsymbol{\Gamma} = \{a_0, a_j, b_{jk}\}$ denotes the parameter vector. Necessary and sufficient parameter restrictions to ensure linear homogeneity in input prices are $a_1 + a_2 = 1$, $\Sigma_k b_{jk} = 0$, $j = 1, 2$, and $b_{1j} + b_{2j} = 0$, $j = 1, \ldots, 7$. Shepherd's lemma can be used to recover factor share equations for the fuel and gear input,

$$(17)\quad \frac{\partial \ln c(\cdot)}{\partial \ln Z_j} = \frac{v_j x_j(\cdot)}{c(\cdot)} = a_j + \sum_{k=1}^{7} b_{jk} \ln Z_k \qquad j = 1, 2$$

where $x_j(\cdot)$ is the demand for input j. Equation (16) and (17) form a system of structural equations that may be used to estimate $\boldsymbol{\Gamma}$. The factor share equations and the cost function are linearly dependent and thus the gear equation is dropped from the econometric estimation.

Data

Data are from several sources: (*i*) the NMFS logbook reporting system, (*ii*) the FMP, (*iii*) the Mid-Atlantic Fisheries Management Council, (*iv*) a survey of industry participants conducted by McCay and Creed, and (*v*) discussions with industry participants. Detailed vessel harvest information is recorded as part of the NMFS logbook reporting system. Vessel-specific cost information from expenditure reports was not available. Instead, per vessel costs were estimated from logbook data and estimates of hourly and per trip costs as reported in the FMP. Quarterly fuel consumption was estimated from an hourly fuel consumption function.[6] Fuel prices for #2 diesel were obtained from the Energy Information Administration (U.S. Department of Energy). Fuel consumption and price were combined to estimate the total quarterly fuel costs for each vessel.

The FMP provides estimates of per trip gear costs for various vessel size classes. These cost estimates were used in conjunction with the fishing trip information from logbook sources to obtain an estimate of the quarterly gear expenditures for each vessel.[7] A detailed gear price was not available and is instead approximated by the gross national product implicit price deflator. All remaining prices are deflated using the gross national product implicit price deflator. Based on calculations obtained from the above procedure, fuel expenses were estimated to be 24% of variable harvesting costs. Gear expenses were estimated to be 76% of variable harvesting costs.

Total exploitable stock estimates are from the *Report of the 19th Northeast Regional Stock Assessment Workshop* (NOAA/National Marine Fisheries Service, available on a yearly basis only). It is assumed that stock abundance does not appreciably change within a given year. Ocean quahog harvest is considered small relative to the exploitable biomass. Moreover, no appreciable variation in ocean quahog stocks occurred during the study period. For these reasons, the quahog stock index was dropped from the empirical specification.

Some ports of departure may be located farther from lucrative clam beds, and thus require additional travel time and fuel consumption.[8] To allow for this possibility, three dummy variables for the two northernmost ports (Point Pleasant and Atlantic City, NJ) and the southernmost port (Cape Charles, VA) are included in the cost equation. The base case (75% of the sample) included ports located in the central region (Chincoteague, VA, Cape May and Wildwood, NJ, and Ocean City, MD).

Vessels that take fewer than 50% of the maximum feasible number of trips per quarter were dropped from the analysis. For these observations, the capital and labor services used in production are likely to be overestimated by the GRT proxy. Vessels exiting the fishery before the end of 1994 were dropped. It is likely that exiting vessels sold quota because they were relatively cost-inefficient. Exiting

[6] Fuel used when the vessel is docked before and after the trip is calculated as engine horse power × 6 hrs. × 0.02. Fuel used steaming to and from the site is calculated as engine horse power × hrs. steaming × 0.04. Fuel used while fishing is calculated as engine plus dredge pump horse power × hrs. fishing × 0.05.

[7] Gear cost estimates range from $526 to $1,044 per trip on surf clam vessels and $526 to $1,699 per trip on ocean quahog vessels.

[8] Vessel operators develop trading relationships with land-based processing firms and rarely change their port of departure. It is assumed that all trips depart from the same port in each quarter.

vessel observations may provide inaccurate information about the cost technology that will prevail under ITQs. Finally, quota redistribution and other adjustments to the ITQ-regime operating rules occurred throughout the data period. It is reasonable to believe observations from later stages provide more information about the ITQ-regime cost structure. To account for this in the analysis, each observation is weighted by a factor $\tau \cdot [\bar{\tau}]^{-1}$, where τ denotes the cumulative quarter since the introduction of the ITQ program, and $\bar{\tau}$ is the sample average.[9]

An error term is added to each observation. The error term is assumed contemporaneously correlated across equations but independent across time and vessels. Each vessel/quarter observation is interpreted as an independent observation on the average harvest technology.

Empirical Results: The Structure of the Harvest Technology

The data included 501 observations.[10] The parameter vector is estimated by the iterative seemingly unrelated regression technique using Gauss software. Parameters found to be statistically different from zero at the 95% confidence level are denoted with an asterisk (table 1). The adjusted R-squared statistic for the cost function equation is 0.99 indicating a very good fit to the data. The fuel share equation does not contain a free intercept term; thus, the related R-square statistic is invalid. To further assess the reliability of the results, the empirical cost function was checked for monotonicity and concavity in input prices. Both requirements were satisfied at all data points.[11] A Wald test of the null hypotheses that the variable cost function is linearly homogeneous in input prices was not rejected at the 95% confidence level. A Wald test of the null hypotheses that the harvest technology (*i*) exhibits constant returns to scale and (*ii*) is separable in outputs were both rejected at the 95% confidence level. Nonjoint-in-inputs implies the existence of output-specific variable cost functions (Denny and Pinto). The null hypothesis that the harvest technology is nonjoint-in-inputs could not be rejected at the 95% confidence level.[12]

The parameters of flexible functions are difficult to interpret. All economic effects are recoverable from the parameter estimates. For the purposes of identifying the ITQ-regime fleet structure, scale and scope efficiency (cost complementarity or anti-complementarity) measures are required. Kim reports multiproduct and product-specific measures of returns to scale for the translog cost function as well as convenient measures of cost complementarity. Space limitations do not permit a complete presentation of these measures. See Kim (pp. 186–93) for further details. Measures of scale economies and cost complementarity are functions of the data. The measures that follow were calculated for a 175 GRT vessel harvesting 35,000 bushels of surf clams and 35,000 bushels of ocean quahogs per quarter. Prices and stock levels were set at 1990 levels. The sign of all reported measures were robust to the evaluation point.

The cost elasticities for surf clams and ocean quahogs [$\partial \ln c(\cdot)/\partial \ln q_j$] equaled 0.31 and 0.29, respectively. All else equal, a 1% increase in surf clam (ocean quahog) harvest results in a 0.31% (0.29%) increase in variable costs. The derivative of the surf clam cost elasticity with respect to additional surf clam harvest is −0.32; the cost elasticity declines as surf clam harvest is increased. The derivative of the ocean quahog cost elasticity with respect to additional quahog harvest is −0.45. The degree of overall scale economies for a multiproduct operation (obtained as the inverse of the sum of the cost elasticities) is 1.66, indicating overall increasing returns to scale. Product-specific scale economies are measured as the ratio of average incremental cost and marginal cost for each output. Based on the necessary calculations, product-specific scale economies were estimated to be 1.04 for surf clams and 1.51 for ocean quahogs. While the surf clam measure is very close to 1 at the point of evaluation, both measures suggest product-specific increasing re-

[9] The study period begins in 1990:4 (τ = 1) and ends in 1994:4 (τ = 22).

[10] A small value (1,000 bushels) is inserted when the quantity of surf clams or ocean quahogs harvest is zero. The results were not sensitive to the value that is inserted for zero output levels.

[11] A necessary and sufficient condition for concavity is that the Hessian matrix of the variable cost function be negative semidefinite. This requirement was satisfied at all data points. The estimated input shares were positive at all data points indicating monotonicity.

[12] The null hypothesis of constant returns and output separability were both rejected at the 95% confidence level. The constant returns to scale, chi-square statistic was 14.28 with critical level 9.49. The output separability, chi-square statistic was 81.24 with critical value 12.59. The nonjoint-in-inputs hypothesis was tested by comparing the likelihood value under the restriction $b_{34} + a_3 \cdot a_4 = 0$. The chi-square statistic was 0.57 with 95% confidence level, critical value 3.84.

Table 1. Parameter Estimates for Translog Variable Cost Function

Parameter	Variable	Estimate	Standard Error	Parameter	Variable	Estimate	Standard Error
a_0	const.	−0.021	0.025	b_{33}	$\ln q_1 \ln q_1$	0.114[a]	0.017
a_1	$\ln v_1$	0.018	0.014	b_{34}	$\ln q_1 \ln q_2$	−0.078[a]	0.013
a_2	$\ln v_2$	0.982[a]	0.036	b_{35}	$\ln q_1 \ln z$	0.007	0.031
a_3	$\ln q_1$	−1.599	1.649	b_{36}	$\ln q_1 \ln S_1$	0.340[a]	0.368
a_4	$\ln q_2$	0.421	1.499	b_{44}	$\ln q_2 \ln q_2$	0.075[a]	0.016
a_5	$\ln z$	4.325	6.196	b_{45}	$\ln q_2 \ln z$	−0.132[a]	0.030
a_6	$\ln S_1$	1.092	8.117	b_{46}	$\ln q_2 \ln S_1$	0.132	0.338
$b_{11} = -b_{12}$	$\ln v_1 \ln v_1$	−0.088[a]	0.038	b_{55}	$\ln z \ln z$	−1.185[a]	0.238
$b_{22} = -b_{12}$	$\ln v_2 \ln v_2$	−0.088[a]	0.044	b_{56}	$\ln z \ln S_1$,	0.654	1.393
$b_{13} = -b_{23}$	$\ln v_1 \ln q_1$	0.017[a]	0.004	b_{66}	$\ln S_1 \ln S_1$	−1.986	3.628
$b_{14} = -b_{24}$	$\ln v_1 \ln q_2$	0.023[a]	0.004	D_1	PP	−0.060	0.040
$b_{15} = -b_{25}$	$\ln v_1 \ln z$	−0.014[a]	0.017	D_2	AC	−0.014	0.029
$b_{16} = -b_{26}$	$\ln v_1 \ln S_1$	0.028	0.017	D_3	CCH	0.124[a]	0.033

Source: Estimated.

Note: D_1 (*PP*) is the dummy variable for home port at Point Pleasant, NJ; D_2 (*AC*) is the dummy variable for home port at Atlantic City, NJ; and D_3 (*CCH*) is the dummy variable for home port at Cape Charles, VA.

[a] The parameter is different from zero at the 95% confidence level.

turns to scale. Note that increasing returns to scale over observed output levels is not unexpected. If fleet adjustments are incomplete, some fishers may be quota constrained and forced to continue to operate in regions of increasing returns. Earlier it was suggested that operating in regions of decreasing returns is equally unlikely.

Cost complementarity or anticomplementarity can be determined by examining the cross derivatives of the cost elasticities, $(\partial/\partial q_j)\{\partial \ln c(\cdot)/\partial \ln q_i\}$, $i = 1, 2, i \neq j$. If $(\partial/\partial q_j)\{\partial \ln c(\cdot)/\partial \ln q_i\} < 0$, ($>0$), an increase in q_j reduces (increases) the cost elasticity for q_i, indicating cost complementarity (anticomplementarity) among outputs. The cross derivative of the surf clam (ocean quahog) cost elasticity with respect to ocean quahog (surf clam) production is 0.05 (0.05). Hence, the estimated variable cost function exhibits scope diseconomies at the output vector of 35,000 bushels of each clam species. To ensure that the cost anticomplementarity finding was robust, several output vectors were evaluated. The results were similar in both sign and magnitude.

Following Panzar, a measure of the degree of scope economies is obtained by calculating the percentage change in cost under multioutput versus single-output production. Harvesting 70,000 bushels of surf clams and 70,000 bushels of ocean quahogs on two specialized vessels rather than two diversified vessels results in a $12,378 (6%) variable cost savings. While the degree of scope diseconomies does not appear large, it must be considered in identifying the ITQ-regime fleet structure.

All remaining economic effects, except for the surf clam stock effect, conform to expectations. The cost elasticities with respect to the price of fuel and gear are 0.28 and 0.72, respectively. The elasticity of substitution between fuel and gear is 0.28, indicating nonzero input substitution possibilities. The derivative of the cost elasticity with respect to GRT indicates that a 1% increase in GRT results in a 0.28% decline in variable cost. The derivative of the surf clam (ocean quahog) cost elasticity with respect to GRT is −0.26 (−0.70). As expected, both elasticity estimates decline with larger GRT.

The cost elasticity with respect to the surf clam stock level is 0.63, which is not the expected sign. A Wald test of the null hypothesis that the surf clam stock effect is zero could not be rejected at the 95% confidence level. The inability to identify cost-reducing stock effects may be due to lack of stock variability over the four-year study period. Dummy variables for home-port cost effects, D_1–D_3 in table 1, indicate a significant variable cost increase for vessels originating from Cape Charles, Virginia, and no appreciable cost differences for the remaining ports.

In summary, the variable cost technology exhibits overall and product-specific increasing returns to scale, cost anticomplementarity, and is nonjoint-in-inputs. Only the latter finding is supported by a statistical test. The variable cost technology favors specialized pro-

Table 2. Hull Values, Maximum Harvest Capacity and Fixed Costs

				Maximum Harvest Capacity				Fixed Costs ($)			
		Labor		Max. Trips/ Qtr.		Max. Catch/Qtr.		Total FC (Per Qtr.)		Min. AFC	
GRT	Hull Value ($)	SC	OQ	SC	OQ	SC	OQ	SC	OQ	SC	OQ
100	129,333	3	4	35	30	29,120	24,960	37,045	43,939	1.29	1.76
125	213,416	4	5	40	35	40,960	35,840	48,705	54,695	1.19	1.53
150	401,503	4	5	45	40	57,600	51,200	57,958	63,478	1.01	1.24
175	529,687	4	5	50	45	76,800	69,120	64,516	69,566	0.84	1.01
200	563,744	4	5	50	50	96,000	96,000	66,838	71,418	0.70	0.74

Source: Logbook data sources and industry participants.
Notes: SC denotes surf clam, OQ denotes ocean quahog, FC denotes fixed cost, Min. AFC denotes minimum attainable average fixed cost (at maximum capacity). Catch is in bushels.

duction. In the absence of product-specific fixed costs, a specialized clam fleet should be expected to emerge under the ITQ management regime. A final step in identifying the number of vessels under ITQs is to combine variable and fixed cost information to determine the long-run cost-efficient output level.

Fixed Costs

Remaining costs are associated with the vessel capital and labor services. Vessel maintenance and capital cost estimates are obtained from the FMP. Maintenance costs include (*i*) costs associated with haul-out and maintenance, required, on average, every 1.5 years at $22,600, $33,900, and $44,200 for class one (<50 GRT), class two (50–100 GRT), and class three (>100 GRT) vessels, respectively; (*ii*) administrative expenses, approximated at 2% of gross revenues; (*iii*) professional services such as legal and accounting costs: $5,650; (*iv*) docking fees: $2700 annually; and (*iv*) miscellaneous expenses: $3,390 per year. Vessel capital costs include (*i*) hull insurance at 5.5% of hull value, (*ii*) interest payments, and (*iii*) depreciation costs. It is assumed that capital markets are efficient, and interest payments reflect the foregone value of vessel capital. An interest rate of 10% is used. Following the FMP, depreciation is approximated linearly over a thirty-year life of the vessel.

Average crew sizes were obtained from the Mid-Atlantic Fisheries Management Council. Labor remuneration was adjusted in the transition to ITQs (McCay and Creed). The previous share system (wherein 33% of vessel revenues were paid to the captain and crew) no longer reflected the market wage under ITQs because vessel catch rates and revenues increased. It is reasonable to assume that adjustments to the wage will proceed until an equilibrium wage or share emerges to reflect the outside earning opportunities for crew labor. An average salary ($22,716) for Mid-Atlantic States was obtained from the U.S. Department of Labor, *Employment and Earnings* statistics. Personal and indemnity insurance, $4,520 per crew, was added to obtain an estimate of the annual wage rate (FMP).

Estimates of maximum per period harvest capacity and average hull values were obtained from industry members and the Fisheries Management Council. Table 2 reports crew size, maximum capacity and fixed cost estimates for representative vessel size classes. All values reported in table 2 were validated from discussions with industry participants.

Quarterly fixed costs were divided by the maximum harvest capacity to obtain an estimate of the minimum attainable average fixed cost (AFC). Note that smaller vessels have lower fixed costs but significantly smaller maximum harvesting capacities. Larger vessels are able to spread fixed costs over larger outputs, and as a result attain lower AFC. Surf clam average fixed cost is $1.32 per bushel for a 100-GRT vessel operating at maximum capacity. Minimum attainable AFC declines to $0.70 per bushel on a 200-GRT vessel. Because an additional crew member is used on board ocean quahog vessels, the minimum attainable AFC is $1.83 on a 100-GRT vessel and declines to $0.75 on a 200-GRT vessel. Given the finding of increasing returns to scale for the variable cost function and declining AFC, it is expected that larger vessels will attain greater total cost efficiency under ITQs.

ITQ Regime Fleet Structure and Returns to ITQ Management Reform

Identifying the ITQ-regime fleet structure requires estimates of average total cost (ATC) minimizing output levels. For a specialized fleet, the number of vessels is then obtained by calculating the smallest fleet size that remains capable of harvesting the TAC in the fishery. The quarterly TAC is set at 712,500 bushels of surf clams and 1,325,000 bushels of ocean quahogs (FMP).

The quarterly TAC for each species was divided by different fleet sizes to obtain an estimate of the average per vessel harvest. ATC is calculated as the sum of fixed and variable costs (from table 2 and the fitted variable cost function, respectively) divided by the implied harvest level. This procedure was repeated for 150, 175 and 200 GRT vessel classes.[13] Average cost estimates on smaller vessels (<150 GRT) exceed the cost estimates for the 150 to 200 GRT vessel classes and are not reported.

Per vessel output, average variable cost (AVC), ATC, and total fleet cost estimates for various fleet structures are reported in table 3. To show the efficiency benefits from quota consolidation, harvest levels and costs are reported for incrementally smaller fleet sizes, ending with the smallest feasible fleet size. For example, a fleet of eight 200-GRT vessels is the smallest that is capable of harvesting the surf clam TAC and thus smaller surf clam specialized fleets were not considered.

Surf Clam Vessels

At a fleet size of twenty-five boats, the per vessel allocation of the TAC is 28,500 bushels per quarter. At this output level, vessels are operating below efficient scale so ATC remains high. Because of increasing returns to scale, AVC and ATC decline as fleet size is decreased. For example, the ATC for a 200-GRT vessel is $4.11 at a harvest level of 28,500 bushels per quarter (output corresponding to a twenty-five-vessel fleet). ATC for a 200-GRT vessel declines to $1.94 per bushel at a harvest level of 89,063 bushels per quarter (the output level corresponding to an eight-vessel fleet).

The estimated quarterly fleet costs indicate the cost savings from smaller fleet sizes. A fleet consisting of twenty-five, 150-GRT boats can harvest the TAC at a quarterly cost of $2.6 million ($2.9 for 175- and 200-GRT vessels). Fleet costs decline as the number of vessels in the fleet is reduced and the total harvest is consolidated onto fewer boats. At a fleet size of ten vessels, for example, each vessel harvests 71,250 bushels per quarter, and ATC is $2.15 and $2.21 for 175- and 200-GRT vessels, respectively. (Note that 71,250 bushels per quarter exceeds the maximum output level for a 150-GRT vessel and thus a ten-boat 150-GRT fleet is not feasible.) The cost analysis reveals that the surf clam portion of the ITQ-regime fleet will consist merely of eight 200-GRT vessels that harvest 89,063 bushels of surf clams per quarter. The corresponding fleet cost is $1.4 million per quarter.

Ocean Quahog Vessels

Similar results are indicated for ocean quahog vessels. ATC declines as the number of vessels is reduced and per vessel harvest is increased. ATC attains a minimum of $2.04 per bushel when harvested by thirteen 200-GRT vessels. The quarterly fleet cost for the ocean quahog specialized vessels is $2.5 million. Combining surf clam and ocean quahog boats, the ITQ-regime fleet will be comprised of eight 200-GRT surf clam vessels and thirteen 200-GRT ocean quahog vessels. The total harvest cost incurred is $1.4 + $2.5 = $3.9 million per quarter or $15.6 million annually.

Diversified Fleet Structure

For comparison, table 3 reports per vessel and fleet cost for a fully diversified fleet structure.[14] As with specialized vessels, ATC declines as per vessel output increases. However, a diver-

[13] The 150-, 175-, and 200-GRT vessel classes are representative of the clam fleet active in 1994. Of the fifty active vessels in 1994, six were 87.5-GRT or less, five were 100-GRT (includes 87.5- to 112.5-GRT), fourteen were 125-GRT, 9 were 150-GRT, twelve were 175-GRT, and four were 200-GRT.

[14] The output mix for diversified vessels is obtained by minimizing total fleet cost conditional on a fully diversified fleet structure. Note that a mixed fleet structure would incur a lower total harvest cost. The cost estimates in table 3 are presented to illustrate the additional savings from specialized production.

Table 3. Harvesting Costs Estimates: ITQ-Regime Clam Harvesting Fleet

Surf Clam Portion of Specialized ITQ-Regime

	Per Vessel Catch (Bushels/Qtr.)		Per Vessel Costs						Quarterly Fleet Cost ($ Millions)		
			GRT = 150		GRT = 175		GRT = 200		GRT = 150	GRT = 175	GRT = 200
Boats	SC	OQ	AVC	ATC	AVC	ATC	AVC	ATC			
25	28,500	0	1.69	3.71	1.79	4.01	1.84	4.11	2.6	2.9	2.9
20	35,625	0	1.54	3.15	1.63	3.41	1.68	3.50	2.2	2.4	2.5
15	47,500	0	1.38	2.59	1.46	2.79	1.50	2.86	1.8	2.0	2.0
10	71,250	0	nf	nf	1.27	2.15	1.30	2.21	nf	1.5	1.6
8	89,063	0	nf	nf	nf	nf	1.21	1.94	nf	nf	1.4

Ocean Quahog Portion of Specialized ITQ-Regime Fleet

	Per Vessel Catch (Bushels/Qtr.)		Per Vessel Costs						Quarterly Fleet Cost ($ Millions)		
			GRT = 150		GRT = 175		GRT = 200		GRT = 150	GRT = 175	GRT = 200
Boats	SC	OQ	AVC	ATC	AVC	ATC	AVC	ATC			
30	0	44,167	1.85	3.35	1.81	3.44	1.73	3.40	4.4	4.6	4.5
25	0	53,000	1.73	2.98	1.68	3.04	1.61	2.99	4.0	4.0	4.0
20	0	66,250	1.59	2.59	1.54	2.63	1.47	2.58	3.4	3.5	3.4
15	0	88,333	nf	nf	1.39	2.20	1.32	2.15	nf	2.9	2.8
13	0	94,643	nf	nf	nf	nf	1.28	2.06	nf	nf	2.5

Fully Diversified ITQ-Regime Fleet

	Per Vessel Catch (Bushels/Qtr.)		Per Vessel Costs						Quarterly Fleet Cost ($ Millions)		
			GRT = 150		GRT = 175		GRT = 200		GRT = 150	GRT = 175	GRT = 200
Boats	SC	OQ	AVC	ATC	AVC	ATC	AVC	ATC			
40	17,812	33,125	1.68	2.81	1.66	2.90	1.60	3.00	6.0	6.1	5.6
35	20,357	37,857	1.60	2.58	1.57	2.65	1.51	2.74	5.5	5.6	5.6
30	23,750	44,166	nf	nf	1.47	2.40	1.42	2.47	nf	5.1	5.0
25	28,500	53,000	nf	nf	nf	nf	1.31	2.19	nf	nf	4.5
22	32,386	60,227	nf	nf	nf	nf	1.25	2.02	nf	nf	4.1

Source: Estimated.
Notes: "nf" indicates nonfeasible output level. AVC indicates average variable cost. ATC indicates average total cost. GRT indicates vessel gross registered tonnage.

sified operation will be unable to fully exploit product-specific returns to scale, and thus cannot match the cost efficiency of a specialized operation. For example, the estimated (short-run) marginal harvesting cost on a specialized surf clam vessel (200-GRT vessel and an output level of 89,063 bushels per quarter) is $0.79. The estimated surf clam marginal harvesting cost on diversified vessel operation (200-GRT and an output level of 32,386 bushels of surf clams and 60,227 bushels of ocean quahogs per quarter) is $0.98. A diversified fleet consisting of 22 200-GRT vessels is estimated to incur a quarterly fleet cost of $4.1 million. This is $0.9 million more per year than under the specialized fleet structure.

Efficiency Gains under ITQs

Fleet cost estimates from table 3 can be compared to costs incurred under LE. McCay and Creed report the total labor force under LE to be 207 individuals in 1990. Using this estimate of total labor, per vessel harvest costs were estimated following the above procedure and summed over active LE-regime vessels. The cost incurred by the LE-regime fleet is estimated to be $28.4 million in 1989.[15] A comparison to the ITQ-regime cost estimate

[15] The last complete year of LE management was 1989. Fleet costs were estimated to be $22.9 million in 1987 and $27.6 million in 1988.

indicates a harvest sector cost savings of \$12.8 million annually. While these gains may seem remarkable, it should be remembered that 128 vessels actively harvested clams in 1989. Apparently the fleet was roughly six times larger under LE than is expected under the ITQ management regime.

Sensitivity Analysis

Assessment of the ITQ fleet structure and the efficiency gains relies on an accurate estimate of the harvest cost structure. Empirical errors can occur at various stages of the analysis. In this study, cost data were measured indirectly from information on fishing times and fishing trips per calendar period. Systematic bias in these data could result in misspecification of the ITQ-regime cost and fleet structure and bias estimates of efficiency gains. Other sources of error include econometric misspecification and poor estimates of stock abundance. It is difficult to determine the net impact of error on the final efficiency gain estimates. Thus, results reported here must be viewed accordingly.

One source of error is the estimate of per vessel maximum harvest capacity. If per vessel capacity is overestimated, the ITQ-regime fleet may consist of more that eight 200-GRT surf clam and thirteen 200-GRT ocean quahog vessels. In this case, the harvesting cost incurred by the ITQ-regime fleet will be underestimated. If, instead, ten surf clam and fifteen ocean quahog vessels are required to harvest the TAC, the quarterly costs for the fleet would rise to roughly \$4.3 million per quarter and \$17.3 million annually (table 3). The efficiency gains under ITQs are reduced to \$11.1 million per year.

A more encouraging observation is that it may not be necessary to identify all aspects of the ITQ-regime fleet structure to obtain a reasonable estimate of the efficiency gains under ITQs. Further examination of table 3 indicates that ATC costs decline sharply as per vessel output is increased. In contrast, vessel GRT impacts ATC estimates to a lesser degree. The ATC at 71,250 bushels per quarter is \$2.20 for a 175-GRT vessel and \$2.15 for a 200-GRT vessel. Identifying the ITQ-regime vessel size appears to be less critical than identifying the efficient scale of operation and the corresponding minimum ATC. Any vessel that can match the minimum ATC is viable under ITQs. For example, differences in fishing skill, which were not modeled in this article, may lead to comparable cost efficiency on different-sized vessels or at different output levels. The ITQ-regime fleet structure may be heterogenous except with respect to the residual return from owning the ITQ asset. See Anderson for further discussion of fisher heterogeneity under an ITQ management program.

A second encouraging observation is that the findings in this article appear consistent with ancillary information and observed trends in the MA clam fishery. First, logbook data indicates that eighteen of the fifty (36%) active vessels in 1994 took fewer than half of the maximum number of trips per quarter. This suggests that the harvesting capacity of a fifty-vessel fleet exceeds the TAC. This evidence is consistent with the prediction that 21–25 vessels will make up the ITQ-regime fleet. Second, the Overview of the Surf Clam and Ocean Quahog Fisheries and Quota Recommendations for 1997 and 1998 reports that clam fishers continue to adjust quota holdings to focus on single-species production. This further supports the prediction of a specialized ITQ-regime fleet structure.

Conclusion

The post-restructuring efficiency gains provide the appropriate benchmark for assessing ITQ fisheries management policy. We present a methodology to estimate harvest sector efficiency gains from ITQs, in lieu of delayed fleet restructuring. A model of equilibrium fleet structure is presented to identify the number of vessels and individual output that is expected to emerge under ITQs. Harvest-sector costs based on the anticipated ITQ-regime fleet are then estimated to provide a post-restructuring assessment of the efficiency gains. The methodology is applied to the MA clam fishery.

While data limitations may have influenced the final estimates of the efficiency gains in this study, the results illustrate the importance of considering long-run fleet adjustments when assessing efficiency gains from ITQs. A long history of capital replacement restrictions in the MA clam fishery led to a fleet structure that bore little resemblance to that expected under the ITQ program. The analysis of this article suggests that roughly 21–25 vessels will remain active under the ITQ-regime as compared to 128 vessels under the previous LE program. The total harvest cost savings under the ITQ program is estimated to be between $11.1 million and $12.8 million annually.

In this study, estimates of efficiency gains were obtained after the ITQ management scheme was implemented. Clearly, *ex ante* estimates would be invaluable to resource managers who are considering ITQ programs. The methodology used in this article may be applied, but the analysis should proceed with caution. Harvesting activities and costs may be strongly influenced by existing regulations. For example, Lipton and Strand estimated harvesting costs and equilibrium fleet structure in the MA clam fishery during the LE regime. Their analysis suggested an equilibrium fleet structure consisting of 149 multispecies vessels in which each vessel harvested 14,933 of surf clams and 56,134 bushels of ocean quahogs annually (Lipton and Strand, p. 205). The stark difference in fleet structures can be explained by vastly different management systems. Future research that focuses on methods to extrapolate ITQ-regime cost and fleet structures from pre-ITQ regime data sources could provide robust estimates of the efficiency gains expected from an ITQ management program.

Additional policy questions emerge from the analysis in this article. Indications are that prolonged fleet restructuring in the MA clam fishery continued to dissipate available rents even four years after the ITQ program was implemented. Further policy actions designed to expedite fleet restructuring may be warranted. For example, an initial quota auction rather than a gratis initial allocation to active fishery participants could hasten industry restructuring. Furthermore, our analysis suggests that production activities during the pre-ITQ management regime may hold little resemblance to the production activities expected under ITQs. Basing initial quota allocations on pre-ITQ harvest levels may in fact prolong the transition to the equilibrium quota distribution and the equilibrium ITQ-regime fleet structure and reduce the possible benefits of ITQ programs.

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