

Economic impacts of individual fishing quota management in the pacific coast groundfish fishery

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Abstract

This paper characterizes anticipated changes in fleet structure, individual vessel harvesting activity, and economic performance in the pacific coast groundfish fishery under an individual fishing quota management program. Results suggest that the current fleet of 117 vessels will be reduced by roughly 50% - 66% to 40-60 vessels, resulting in annual cost savings of \$18 - \$22 million (based 2004 price and cost estimates). However, cost savings could be significantly less if restrictions on quota trading across vessels are incorporated into the program design. Alternative modes of taxing fishing revenues to fund program administration and their impact on fleet size and total fishery value under quota management are also studied. We conclude that individual fishing quotas can be an attractive alternative for management of the pacific coast groundfish fishery.

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1 Introduction

The pacific coast groundfish fishery (PCGF) is currently managed under a controlled access management program. Commercial harvesting activities are regulated with vessel entry restrictions, gear restrictions, area closures, seasonal closures, and bi-monthly (per-vessel) catch limits. These regulations are intended to prevent overfishing of groundfish stocks, in particular species which have been identified as overfished or subject to overfishing. By design, controlled access regulations reduce harvesting efficiency of vessels, which raises the cost of harvesting groundfish. Furthermore, controlled access management fails to align fleet harvesting capacity with catch targets, is costly to administer, and in the case of pacific groundfish introduces incentives to discard fish at sea (Branch et al., 2006). Overall the controlled access program has failed to meet key management objectives, which in turn has prompted calls for an alternative management approach which might improve economic and biological conditions in the fishery.

This paper examines the economic implications of adopting an individual fishing quota (IFQ) management program for the limited entry trawl component of the pacific coast groundfish fishery. The limited entry trawl component of the pacific coast groundfish fishery accounts for about 70% (on an ex vessel revenue basis) of the groundfish harvested on the pacific coast (California, Oregon, and Washington). The specific goal of the paper is to provide an *ex ante estimate* of changes in fleet structure and profitability that is expected if controlled access is replaced by IFQs for the limited entry trawl fleet. For reasons of data availability explained below, this paper focuses on the non-whiting component of the limited entry trawl fleet. The regulatory regime in other portions of the pacific coast groundfish fishery, including the limited entry fixed gear fleet and the open access fleet, is assumed to remain unchanged.

The conceptual approach follows recent work by Weninger and Waters (2003) and Singh et al. (2006). In a first step we used data on operating expenses and catch of groundfish vessel operations to estimate vessel level harvesting costs. Exploiting the economic incentives implicit in IFQ operating rules for groundfish fishermen we then predict the number and type (length class) of vessels expected to participate in an IFQ-managed groundfish fishery. The analysis allows us to estimate harvesting cost savings, or resource rents that are expected to emerge in the PCGF under IFQ management.

Our data and analysis are focused on the limited entry trawl vessel fleet excluding the whiting sector, which hereafter is referred to simply as the *groundfish fleet*. Results suggest that the current groundfish fleet which consisted of 117 vessels in 2004-05 will be reduced by roughly 50 - 66% to 40-60 vessels under an IFQ program. The significant reduction in fleet size will result in costs savings in the fishery in the range of \$18 - \$22 million in 2004 (most recent year of the data). Vessels that remain active will on average be more cost efficient and will benefit from economies of scale that are currently unexploited under controlled access regulations in the PCGF . The cost savings estimates

are significant, amounting to 60% of costs incurred currently, suggesting that IFQ management may be an attractive option for the PCGF.

Our analysis reveals however that projected cost savings are sensitive to the design elements of the IFQ program. In particular, we show that restrictions on the total quota that can be harvested by individual vessels, or restrictions on quota trading across vessel length classes can significantly reduce the estimated benefits (cost savings) of switching to IFQs. We find that benefits decline by roughly \$3.80 million (18.4%) per year if a 1% cap on quota ownership is imposed, and by as much as \$2.14 million (10.4%) per year under restrictions on harvest permit trading across vessel classes.

Results further show that program design elements have implications for the vessel length classes that will remain active in an IFQ-managed groundfish fishery. As one might expect, tight harvest quotas on individual vessels favors smaller boats due to their lower fixed costs. Restrictions on permit trading across vessel classes will keep vessels active that would otherwise exit the fishery, and will reduce resource rents that are generated under the IFQ program.

A less obvious finding concerns the mode of rent collection for administering the IFQ program. Current program designs include 100% coverage of groundfish trips by on-board observers, with costs collected from participants in the IFQ program. We show that charging vessel operators directly for observer costs, on a days-at-sea basis, favors larger vessels. Large vessels harvest more fish per day than small vessels and thus incur lower observer cost per landed pound. Collecting observer costs from active boats lowers profits which leads to a smaller IFQ-regime fleet and lower fleet harvests. Collecting rents to pay for observers through landings taxes lowers both the harvest quantity as well as the fleet size. Our results however show that it is only the non-DTS species, which receive a lower price at the dock, whose harvest drops as a result. When these taxes are uniformly levied on a per-pound basis, the effective non-DTS prices drops relatively more and its harvest decline is larger. Since smaller boats run closer to their physical harvest capacities, their costs (inclusive of taxes) rise relatively more under landing taxes. Once again, as a result, landing taxes tilt the fleet size towards larger vessels, albeit to a less extent than that under days-at-sea basis.

The next section presents a conceptual model of the IFQ fishery and highlights the economic incentives that underlie an IFQ management program. Section 3 discusses the data and presents the cost analysis and results. Section 4 investigates the equilibrium fleet structure and resource rents in a dynamic fishery where total available harvests are uncertain. Section 5 summarizes the key findings and offers concluding remarks. Additional background material on rent generation under controlled access and IFQ regulations is presented in an appendix.

2 The Model

We will consider a multiple-species IFQ management program. To fix ideas, we begin with a static and deterministic analysis; fleet structure in a dynamic uncertain harvesting environment is examined in Section 4.

The manager issues species-specific harvest permits which grant their owner a right to catch a specified quantity of fish. Production periods are distinguished with a subscript t . The total permits issued and thus the total allowable harvest in period t is denoted Q_{mt} for species $m = 1, \dots, M$. The biomass in the fishery is denoted X_{mt} for species m . Catch cannot exceed biomass and thus, $Q_{mt} \leq X_{mt}$ for all m .

Denote the quantity of species m fish landed by vessel operation i in period t as q_{mt}^i . We assume that the manager is able to monitor the total landings in the fishery. Total landings cannot exceed total available permits;

$$(1) \quad \sum_i q_{mt}^i \leq Q_{mt}, \text{ for all } m = 1, \dots, M, \text{ for all } t.$$

Note that the summation in 1 is over the vessel operations that landed species m fish in period t . Species m fish is sold at period t dockside price p_{mt} .

To simplify notation we will hereafter consider a representative vessel operation and a representative production period. We also let $Q = (Q_1, \dots, Q_M)$ denote the vector of total harvest permits, $X = (X_1, \dots, X_M)$ denote the vector of stock levels, $q = (q_1, \dots, q_M)$ denote the harvest vector, and $p = (p_1, \dots, p_M)$ denote the vector of dockside prices.

Variable fishing costs are defined over the harvest vector q :

$$c(q, X) = \min_z (w'z | (z \text{ can harvest } q \text{ given } X)),$$

where z is a vector of variable inputs (e.g., fuel, labor, gear, bait and ice), and w is a vector of input prices. Lastly, we allow for heterogeneity in the ability to harvest fish at the least cost; in particular, the fishing cost for a vessel operation with skill level k is $c_k(q, X)$.

It is useful to contrast minimum costs under IFQ management with that under a limited entry (LE) management.¹ Under the latter, the maximum number of active vessel operations is fixed through entry permits. In practice, the number of permits issued by the management authority is arbitrary; typically determined as the number of boats active in the fishery when the LE program is introduced. Since managers in addition also aim to control the total fish harvest (i.e. satisfy the constraint in (1)), restrictions on harvesting activities are required to ensure that total fleet harvest does not exceed their target. Thus, due to the arbitrariness of entry permits and consequent ad-hoc

¹See appendix for a more detailed discussion.

operational restrictions, LE management does not align the fleet size, i.e. active vessel operations, with the target catch in a way that is capable of minimizing harvesting cost (or maximizing resource rent).

IFQ management, on the other hand, aims to control directly the total harvest in the fishery. We assume that there are no restrictions on IFQ ownership, and that the IFQ program is *closed* in the sense that harvest of all fish species require IFQ permits. These assumptions imply:

$$c_k^{IFQ}(q, X) \leq c_k^{LE}(q, X).$$

In other words, relative to the costs under a limited entry management, harvesting costs for a given stock abundance and skill level can only decline under an IFQ program.

We assume that a k -type vessel capital can be employed to an alternative use outside of the fishery, in which case it earns a per-period variable profit, $\psi_k \geq 0$. The total profits of the vessel operation are thus given as $\pi_k(q, X) - \psi_k$, where

$$\pi_k(q, X) = pq - c_k(q, X).$$

The decision to be an active participant in the IFQ-managed fishery must consider two opportunity costs. The first is the cost of the vessel capital, ψ_k . The second is the cost of owning IFQ harvest permits. This latter cost exists with IFQ management because harvest permits have value. To see this formally, suppose the manager issues species-specific permits that grant the right to harvest Q_m units of species m fish, $m = 1, \dots, M$. The owner of harvest permits are the residual claimant of the excess profit that can be generated by harvesting and selling fish. High cost vessel operations will earn less profit than low cost boats, and will face an incentive to sell their permits and exit the fishery.² This incentive will exist regardless of who owns the IFQ shares.

Assume that a well-functioning permit trading market emerges under IFQ management. Let $r = (r_1, r_2, \dots, r_M)$ denote the vector of permit lease prices. For all active vessels in the IFQ fishery the following conditions must hold:

$$(2) \quad \begin{aligned} \pi_k(q, X) - \psi_k - r'q &\geq 0 \\ \frac{\partial c_k(q, k, X)}{\partial q_m} &= p_m - r_m, \\ \sum_i^{N^{IFQ}} q_m^i &= Q_m, \quad m = 1, \dots, M, \end{aligned}$$

where N^{IFQ} denote the number of active vessel operations.

The first condition states that all active vessels must earn non-negative profits, where profits

²Permits under LE management also have a value. See Appendix 7.2 for a detailed analysis.

explicitly include the per-period permit holding cost, $r'q$. We can rank the population of vessel operations from the lowest to the highest cost. Let \hat{k} denote the cost efficiency level/type of the $N^{IFQ} + 1$ vessel operation, i.e., this is the lowest cost vessel among those that do not participate in the IFQ fishery. If this vessel did enter the IFQ fishery, it could earn operating profits given as,

$$\max_q \{\pi_{\hat{k}}(q, X) - \psi_{\hat{k}}\}.$$

Denote the harvest vector that maximizes profits for this vessel operation as $q_{\hat{k}}$. To enter under IFQs, the vessel must acquire permits to legally land $q_{\hat{k}}$ units of fish. By assumption, however, this vessel has higher costs than all active vessels, and thus will earn a lower per-period profit than other active vessels, and consequently cannot profitably purchase harvest permits from an active operation. We see that the first condition in 2 implies an entry-exit equilibrium.

The second condition in 2 ensures that the gains from permits trades among active vessel operations are exhausted. The third condition is simply a restatement of (1).

The conditions in 2 reveal three sources of cost savings are expected when LE management is replaced with IFQs. First, lifting the restrictions on harvesting activities will lower harvesting costs for all vessels. Second, per-unit harvesting costs are expected to fall under IFQs as the harvesting responsibilities are carried out by the most efficient (lowest cost) operators in the vessel population. Third, vessels that are active under IFQs have an incentive to exploit available economies of scale and scope in production.

3 Data and empirical estimation

This section describes the data and the econometric analyses used to estimate two model components: (1) the harvesting cost function $c_k^{IFQ}(q, k, X)$ and (2) a dynamic model that describes the species-specific total allowable catch levels in the groundfish fishery, and the corresponding equilibrium fleet structure as described in 2.

3.1 Groundfish harvesting costs

A comprehensive survey of fishing expenses for the 2003 and 2004 groundfish fishing seasons was conducted by the National Marine Fisheries Service. Data collected include captain and crew wages, expenditures on fuel, ice, bait and food, and the costs of repairs, vessel maintenance, and maintenance of gear and equipment that is used while fishing. The survey attempted a census of all limited entry trawl vessel owners, and successfully completed interviews with 111 of them. This represents a response rate of 74% for active limited entry trawl vessel owners. Interviewers elicited information on vessel characteristics including length, fuel capacity, fuel consumption, whether the vessel owner

was also the skipper of the vessel, and the shares used to remunerate the skipper and crew. The data collected by survey on expenses and non-Pacific Coast landings revenue can be combined with PACFIN data on Pacific Coast landings to obtain a complete picture of the costs and revenues for each vessel.

Total vessel costs are separated into variable and fixed cost components. Variable costs include expenditures on crew labor, fuel, bait and ice. Fixed costs will include the annual repairs and maintenance of the vessel, costs of maintaining and replacing lost gear, and the wage of the vessel captain. Two comments regarding this division of the total costs are warranted. First, one might posit that vessel and gear maintenance will be minimal if no fishing takes place, and is thus a *variable* cost. However, our empirical goal is to measure the cost savings that are expected under an IFQ management program, which in equilibrium will involve full utilization of available vessel harvesting capacity. Furthermore, the mechanical components of a fishing vessel do deteriorate even if unused. Interpreting maintenance expenses as a fixed cost thus appears to be reasonable in our empirical setting.

Second, skipper wages are aptly viewed as a variable operating costs. However, an examination of our data revealed that the reported *skipper wage* paid to the owner/operators of a vessel, i.e., the wage that the owner paid himself, was in some cases a token payment that did not reflect a true market wage. These token payments are not comparable to the wage paid to hired skippers. To reduce the effect of this data anomaly on the analysis, we treat the skipper wage as a fixed cost in the analysis that follows. We assume vessel captains are paid the median wage in our data which is \$80,000 annually.

3.1.1 Fixed costs

Cost survey participants were asked to report expenditures on gear and vessel repairs, maintenance, and improvements. Hereafter this expense category will be denoted *mr* (*maintenance and repair*). Respondents were also asked to explain any significant expenditures they listed under this category. The data indicate that reported *mr* expenses varied widely across boats due to the fact that some vessel owners made expensive engine repairs or replaced engine or drive trains parts. It is clear from the data that these types of repairs are incurred only occasionally.

We estimate a simple model to obtain an *expected* value for the *mr* expense category:

$$(3) \quad \ln(mr) = -6.612 + 0.691 \cdot len - 0.029 \cdot len^2 + 0.035 \cdot fuel_cap,$$

where *len* is vessel length and *fuel_cap* is the vessels' fuel capacity. Ordinary least squares is used to estimate the above model (variables have been scaled to simplify the presentation). There were 182 observations. All estimated parameters had low standard errors (each is statistically different

from zero at the 99% level of confidence). The adjusted R-square for the model is 0.472 reflecting the considerable variation in this expense category across vessels and years.³

A second component of annual fixed cost is the rental price of the vessel capital. Our data include survey respondents' self-assessments of the sale value of their vessel. To smooth idiosyncratic differences in reported values, which we denote P_k , we conduct a least squares regression to obtain the following equation,

$$(4) \quad Vval = 1.763 - 0.597 \cdot len + 0.053 \cdot len^2 + 0.026 \cdot fuel_cap.$$

The reported parameter estimates in equation (4) also had low standard errors (each parameter is statistically different from zero at the 99% levels of confidence). The adjusted R-square for the above model is 0.925.

Combining the above results yields an annual fixed cost estimate for the groundfish vessels in our data:

$$(5) \quad \widehat{\psi}(k) = cap_wage + \widehat{mr} + \rho \cdot \widehat{P}_k,$$

where cap_wage is the captain wage and \widehat{mr} and \widehat{P}_k are the fitted values obtained from the above regression models (recall that ρ is an annual interest rate).

3.1.2 Variable operating costs

Industry sources indicate that groundfish landings are determined largely by the demand for fish by groundfish processors. We will assume that the landed quantity of groundfish for each vessel is exogenously determined in this *demand driven* fishery, and that the objective of vessel owner/operators is to minimize the costs of landing the groundfish quantities set by processors.

We will also assume that the cost of harvesting groundfish is influenced by two forces. As discussed previously the skill level of the vessel skipper is potentially an important determinant of harvesting costs. A second factor is the randomness associated with commercial fishing. For example, random weather and marine environmental conditions influence the spatial and temporal distribution of groundfish. The randomness in abundance implies randomness in the observed costs of landing groundfish.

Stochastic frontier econometric methods have been developed to capture these specific features of the production environment, and are well suited to estimate the costs that are expected under IFQ management. A summary of the stochastic frontier model is available in Kumbhakar and Knox

³A dummy variable for 2004 was included in an earlier regression but found to have no significant effect on maintenance and repair costs.

Whiting Boats						
Year	Boats	Ave. Trips	Std. Trips	Ave. Land.	Std. Dev. Land.	Max. Land.
2001	28	45.6	19.5	6,066.3	3,126.6	14,304.7
2002	28	33.9	15.3	4,077.1	1,710.8	7,369.7
2003	32	34.1	14.2	3,185.8	1,478.2	8,101.8
2004	26	52.6	17.6	7,928.3	3,262.4	15,001.7
2005	29	48.0	14.8	7,688.5	3,022.6	14,845.4
2006	34	41.7	18.0	6,018.0	2,960.7	14,803.7
Groundfish (non-whiting) Boats						
Year	Boats	Ave. Trips	Std. Trips	Ave. Land.	Std. Dev. Land.	Max. Land.
2001	234	32.8	21.0	327.4	256.6	1,224.1
2002	231	33.5	22.5	372.6	319.6	1,902.0
2003	226	31.2	22.8	337.3	261.3	1,643.4
2004	143	35.0	24.9	433.8	358.6	2,269.3
2005	140	35.3	23.7	446.6	310.2	1,528.7
2006	137	35.7	22.6	421.3	257.1	1,110.9

Table 1: Whiting and Groundfish Feet Catch Statistics: 2001-06. Ave., Std., and Max. denote respectively the average, standard deviation, and maximum values. Whiting Boats land more than 100,000 pounds of whiting per year. Harvest quantities are thousands of pounds per year.

Lovell (2000). The econometric specification closely follows Hadri (1999).

Empirical tractability requires that fish species be aggregated into output groups. Industry participants and managers were consulted to identify groundfish species that are harvested using similar gear, at similar depth and in similar geographical regions.⁴ It was determined that six output groupings provide a reasonable balance between model tractability and potential inaccuracy resulting from aggregation. Our species groups include (1) Whiting; (2) DTS species, which consist of dover sole, thornyheads, and sablefish; (3) non-DTS species which include all groundfish species that tend to be harvested in depths less than 100 fathoms; (4) crab; (5) shrimp; and; (6) others, which includes salmon, halibut, highly migratory and pelagic species. Harvested quantities within each output category are aggregated linearly. The aggregation procedure assumes that optimal input choices required to harvest these output groups can be chosen independently of the mix of species within each group, or alternatively that the harvest technology exhibits weak output separability. Linear aggregation implies a constant rate of product transformation among species that make up each output group.

Table 1 reports descriptive statistics from 2001-2006. The fleet is divided into Whiting and non-Whiting, or *Groundfish* vessels.⁵ Whiting is harvested with mid-water trawls as opposed to bottom

⁴There are over 82 separate species of groundfish listed in the Fisheries Management Plan.

⁵Whiting vessels are delineated as those harvesting less than 100,000 pounds of Groundfish species annually.

trawls which are used to harvest most of the other groundfish species. Vessels targeting Whiting tend to be larger, and harvest considerably more pounds per trip and per year than do vessels targeting groundfish species. Moreover, fishermen indicate that they are able to target whiting almost exclusively. PACFIN data supports this claim: the share of whiting landings for vessels that target whiting is often in excess of 0.90 and in some cases as high as 0.99. Catch patterns in the data are consistent with feedback from industry who consider whiting boats a separate segment of the groundfish fleet.

Comparing trips and landings per vessel per year in Table 1 highlights the differences between Whiting and Groundfish vessels. In particular, the average and maximum landings for Whiting vessels is an order of magnitude larger than for non-whiting Groundfish vessels.

Table 1 reveals further information about the structure of the groundfish fleet under the current management regime. First note that the number of vessels reporting landings dropped markedly in 2004. The cause of this decline was a government and industry sponsored vessel buyback program which permanently retired 91 trawl Limited Entry permits. The effect of the buyback which reduced the number of Limited Entry permits from 274 to 183, is evident in Table 1. The mean number of trips taken and the harvest per vessel declined during 2001-2003, prior to the buyback (this may explain why the buyback program was supported by managers and industry), and increased during 2004-2006 in the post buyback period.

A final noteworthy aspect of the statistics in table 1 is the variation in the trips per year and the annual harvest among active vessels. For example the maximum harvest quantity is in many years 3-5 times larger than the per vessel average. The standard deviation of trips and landings is also high indicating considerable variation in landed pounds. Some of this variation is explained by differences in vessel sizes, and mix of target species. A second explanation however is variation in vessel capacity utilization, which is common in fisheries managed under limited entry programs (Weninger and Waters, 2003; Singh et al. 2006).

Examination of the cost survey data indicated missing information for some key cost categories (20 observations in 2003, and 13 in 2004). Some vessels (roughly 25) landed a large component of their annual catch in Alaskan waters. The data do not allow us to separate the reported costs into west coast groundfish expenditures and expenditures incurred in Alaskan waters. Thus these vessels were removed from the analysis. Lastly a few vessels had incomplete catch data and some reported unreasonable crew wage information.

The data are an incomplete panel; 62 vessel observations had complete data for both 2003 and 2004, there are 6 additional observations available in 2004, for a total of 130 vessel/season observations. Because there at most 2 observations per vessel, panel data techniques were not used.

3.1.3 Empirical Specification

Variable operating costs for a representative vessel in our sample (as above we avoid vessel subscripts to ease notation) are assumed to follow,

$$(6) \quad \ln c(q, w, k, X) = \beta_0 + \sum \beta_m q_m + \beta_w w_t + \beta_k k + \beta_z z + \beta_x X_t + v + \epsilon.$$

where q_m is an m -vector of landed quantities ($m = 6$), w_t is the fuel price in year t , k is a measure of vessel capital, and z denotes other exogenous factors that may impact variable harvesting costs. The parameters $\{\beta_0, \beta_m, \beta_w, \beta_k, \beta_z, \beta_x\}$ are unknown and must be estimated. Following the stochastic frontier literature, we append an additive composed error term to the right hand of equation (6). The error term denoted ϵ is assumed to be independently normally distributed with zero mean and finite variance; $\epsilon \sim N(0, \sigma_\epsilon^2)$. The error term denoted v is nonnegative and captures the cost inefficiency of harvesting operations. We assume that v is distributed as a half-normal random variable with variance σ_v^2 .

Heteroskedasticity (which is common in panel data) can bias the analysis of inefficiency in stochastic frontier models (Caudill et al., 1995). Heteroskedasticity may be particularly prevalent in commercial fishing data. Table 1 in particular reveals considerable variation in the number of annual fishing trips taken in the groundfish fishery. If one postulates that the catch on each trip is partly random due to unforeseen weather conditions and/or stock abundance, the law of large numbers would suggest that the variance of the two-sided error, σ_ϵ^2 , will be larger for vessels taking fewer trips. Heteroskedasticity in the asymmetric error component may also be important. For example, some vessels may target a different mix of species from year to year which could impact the ability of the skipper to consistently locate fish. The doubly-heteroskedastic cost frontier framework of Hadri (1999) is adopted to capture these elements.

We use two measures of vessel capital; vessel length and fuel capacity. The fuel capacity variable is included as a proxy for the power of the vessels engine and an indication of the size of net that can be dragged through the water and the quantity of fish that can be winched to the vessel deck and hauled back to port.

The components of z include the proportion of time that the vessel owner serves as captain, and the latitude of the vessel's home port. The ownership variable may capture differences in productivity that result from ownership structure. For example, hired skippers tend to be full time fishermen who, due to the fact that they spend more time at sea, may develop better knowledge about the location of high concentrations of groundfish. The latitude variable is included as a proxy for possible differences in stock abundance across geographical regions. It should be noted however that vessels are mobile; if certain regions of the fishery are more productive than others, and information about abundance flowed freely among fishermen, vessels would likely relocate to more productive regions.

Parameter	Variable	Estimate	Standard Error
β_0	Constant	-1.009	1.839
β_1	Whiting	0.052**	0.115
β_2	DTS	1.350**	0.335
β_3	Non-DTS	0.561*	0.232
β_4	Crab	2.932**	0.362
β_5	Shrimp	0.652**	0.227
β_6	Other	1.878	1.563
β_w	Fuel Price	-1.016*	0.556
β_k	Vessel Length	0.127**	0.047
β_k	Fuel Capacity	0.178*	0.078
β_z	Latitude	-1.363	1.073
β_z	Owner-as-skipper	0.294**	0.089
β_{2004}	2004 Dummy var.	-0.236**	0.070
θ_0	Constant (σ_ϵ)	0.020	0.176
θ_1	Trips	-1.154**	0.196
γ_0	Constant (σ_v)	-1.111**	0.406
γ_1	dv	-0.228	0.407
Likelihood Function Value		-64.436	

Table 2: Variable Cost Function Parameter Estimates A single (double) asterix indicates parameter is statistically different from zero at the 95% (99%) confidence level.

The inclusion of the latitude measure may capture short run or out-of-equilibrium differences in regional productivity.

Data on abundance of all groundfish species stocks are unavailable. To capture unobserved stock effects, we replace β_x with β_{2004} and interact this parameter with a dummy variable that is set to unity in 2004 and zero otherwise. Limitations of missing stock data are discussed below.

We assume $\sigma_\epsilon = \exp(\theta_0 + \theta_1 \text{trips})$, where *trips* is the number of trips taken during the fishing year. Similarly, we assume $\sigma_v = \exp(\gamma_0 + \gamma_1 dv)$ where dv is a measure of diversification in the species mix. We compute dv as the sum of squared landing shares. Thus a vessel that specializes in the harvest of one species only would have $dv = 1$, whereas vessels that target a mix of species would have a lower value for this variable.

3.1.4 Results

The likelihood function is estimated in a standard way with GAUSS software (the likelihood function is reported in Hadri, 1999, or Kumbhakar and Knox Lovell, 2000). Parameter estimates and standard errors, along with the likelihood function value are reported in Table 2

Most parameter estimates have expected sign and low standard error. The parameters associated with harvest of the six species groups β_1 through β_6 , are positive and, with the exception of the

other-species group parameter, β_6 , are statistically different from zero at or above the 95% confidence level. The marginal harvesting costs are calculated as $\partial c/\partial q_i = c \cdot \beta_i$. Marginal cost estimates are consistent with information provided by industry, and average dockside prices in the fishery. The marginal cost per pound of whiting, which is the highest volume species, is lowest at \$0.012 (the average dockside price for whiting obtained from the PACFIN data base is \$0.046). Marginal costs for the deeper water DTS group is \$0.162 (average dockside price is \$0.523).⁶ The marginal cost for the non-DTS species group, which is harvested from shallower waters, is estimated at \$0.067 (average dockside price is \$0.305). Our results find that the marginal cost for crab which, based on feedback from industry, is a more labor intensive fishing activity, is \$0.352 (average dockside price is \$0.624). Lastly, the marginal cost for the Other species group is estimated at \$0.225 with average dockside price \$1.085.

The fuel price parameter estimate is negative and significantly different from zero at the 95% confidence level. This wrong sign is likely due to the assumptions that underlie the construction of the fuel price variable. Data limitations require that an annual average fuel price be used whereas fuel prices and consumption do vary seasonally. Furthermore, our data report the home port of the groundfish vessel but do not indicate where the vessel conducts the bulk of its fishing and refueling throughout the fishing season. Lastly, the average fuel price varies very little across ports, and changed by less than \$0.05 per gallon between 2003 and 2004, making identification of the fuel price effect difficult.

The results indicate that the latitude variable has a negative impact on variable costs but that the effect is not significantly different from zero. As noted above, our data do not indicate the location of fishing which complicates the identification of regional stock effects if they do indeed exist. If vessels do fish adjacent to their home port year round, we can conclude from our results that there are no significant differences in productivity across geographical regions in the groundfish fishery.⁷

Hired skippers have lower variable harvesting costs than skippers who are also the owner of the vessel. One explanation for this result is that hired skippers fish more and have better information about the location of high concentrations of groundfish. Our data indicate that vessels with hired skippers harvest almost 4 times more fish per year than owner/operator boats. It is possible that increased harvesting activity allows hired skippers to hone their skill for locating fish and in turn reduce the costs per harvested pound.

The parameter associated with the 2004 dummy variable is negative and statistically difference from zero at the 99% confidence level, indicating that variable costs declined between 2003 and 2004.

⁶ A Tornqvist index is used to calculate the price of multiple species output groups. We then calculate the average price index across vessels which reported positive landings.

⁷ This conclusion does not suggests that abundance is homogenous in the fishery but rather that after controlling for proximity of the fishing grounds from port, weather, etc, that we find no identifiable differences in costs per landed pound of fish across port latitude.

Year	Ave.	25'th %	50'th %	75'th %
2003	0.131	0.073	0.104	0.140
2004	0.117	0.077	0.107	0.138

Table 3: Estimates of Cost Inefficiency

Several factors could cause this finding. First, any factor (biological or economic) that changed between 2003 and 2004 and is not accounted for in the econometric model will influence the estimate of β_{2004} . One such factor may be the permit buyback program which likely retired higher cost vessels from the groundfish fleet. Another cause could be increased stock abundance in 2004. Independent estimates indicate that the stock levels for some key groundfish species did increase between 2003 and 2004 (e.g., Dover and Petrale sole). Without a comprehensive account of abundance for all groundfish species, however, the true cause of the 2004 cost decline cannot be determined.

Turning to the heteroskedasticity terms we find that σ_ϵ^2 is a declining function of the number of trips taken per year. This relationship is as expected. We find no statistically significant heteroskedasticity in the variance of the asymmetric error term, σ_v^2 .

3.1.5 Cost inefficiency

Following Jondrow et al. (1982), we calculate the conditional expected value of cost inefficiency as measured by v . Denote the expected cost inefficiency as $\hat{v} = E[v|v + \epsilon]$.

Table 3 reports the sample average, along with the 25th, 50th and 75th percentile values for \hat{v} from the 2003-04 data. The results indicate that, averaged across sample vessels, variable costs were 13.1% and 11.7% above frontier costs in 2003 and 2004, respectively. Sample average efficiency improved slightly between 2003 and 2004. This result may reflect the effects of the permit buyback program, which likely removed the least efficient boats from the groundfish fleet. However, as discussed above, unaccounted for changes in stock abundance are also consistent with changes in the average performance of the fleet across years.

Sample average inefficiency masks somewhat the distribution of inefficiency across vessels. Figure ?? plots a histogram of vessel-level cost inefficiency measures. The figure indicates a positively skewed distribution in inefficiency which indicates significant inefficiency is present for a small portion of the fleet. This finding is generally consistent with previous studies of harvesting inefficiency in fisheries that are managed under limited entry programs (Weninger and Waters, 2003). The result suggests that cost savings in the form of pure efficiency gains can be expected under an IFQ management program as the bulk of the harvest responsibilities are transferred to the most productive vessels in the fleet. We will turn to the issue of estimating these efficiency gains shortly.

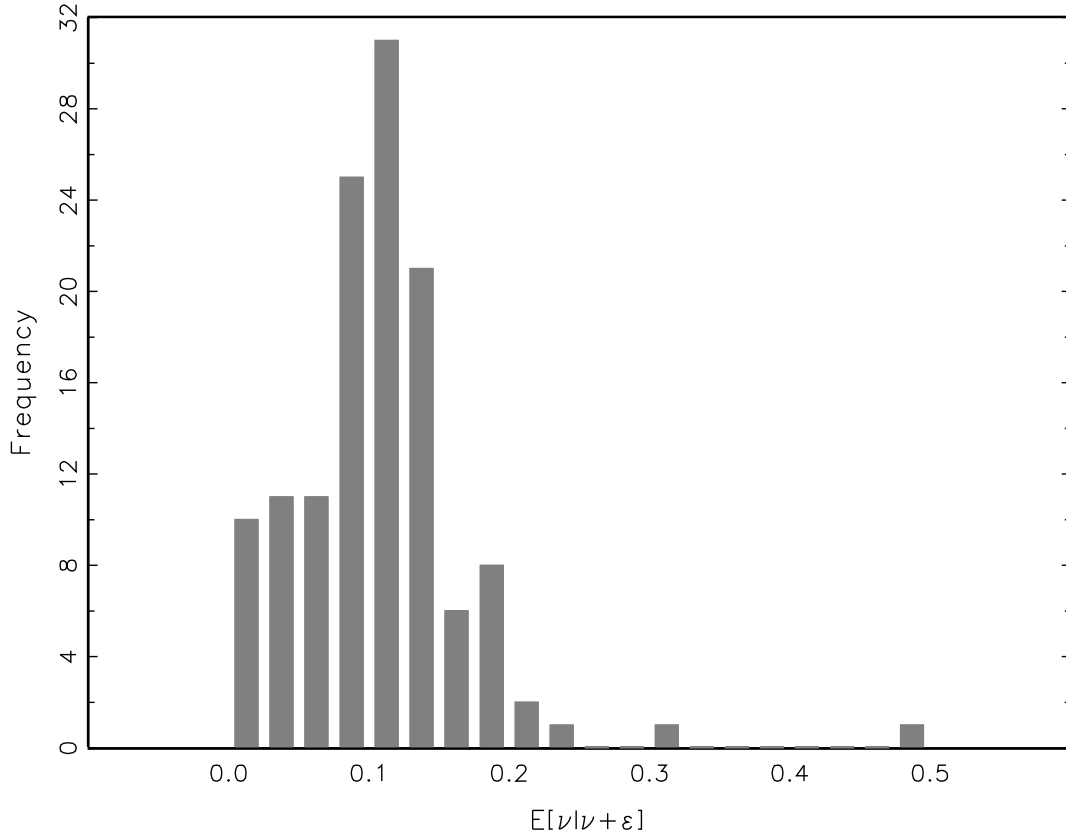


Figure 1: Distribution of Cost Inefficiency in the Sample Data.

3.1.6 Economies of scale

We next consider a second important source of cost savings expected under the IFQ management program, which is economies of scale. A useful measure of multi-output economies of scale is given in Panzar and Willig (1977):

$$S = C(w, q) / \left(\sum_m q_m \frac{\partial C(w, q)}{\partial q_m} \right).$$

In the above $S > 1$ indicates economies of scale exist at harvest vector q , whereas $S < 1$ indicates diseconomies of scale at q . $S = 1$ indicates constant returns at harvest vector q .

We calculate S for all vessels in our sample using variable operating costs and total cost for each vessel. Total costs are calculated as the sum of variable costs plus the *expected* fixed cost as derived in equation (5). We divide the sample into vessels that operate in a region of increasing returns, constant

1	2	3	4	5	6
Obs.	Length	Fuel Cap.	Catch Cap.	Vessel Value	Main./Repair
10	<45	1000.0	500,000	\$188,634	\$93,920
21	50	2587.6	850,000	177,984	102,695
28	60	4576.8	1,500,000	235,675	115,435
28	70	6964.3	1,950,000	361,665	132,977
19	80	1,0631.6	2,250,000	567,044	158,210
4	85+	1,1500.0	2,250,000	800,507	178,878

Table 4: IFQ-Regime Representative Vessels Characteristics Fuel Cap. - denotes vessel fuel capacity in gallons; Catch Cap. - denotes annual harvesting capacity in pounds; Main./Repair - denotes annual maintenance and repair expenditures

returns and decreasing returns to scale. The results indicate that of the 62 sample vessels for with 2003 data are available, 3 boats operated in a region of decreasing returns, 8 operated at constant returns and 51 operated in a region of increasing returns to scale. The 2004 sample observations indicate that 5 vessels operated in a region of decreasing returns, 12 operated at constant returns and 51 operated in a region of increasing returns to scale. For vessels operating under increasing returns, average cost per unit of harvest will decline if the scale of production is increased. Note that this is precisely what is predicted to occur in the groundfish fishery as the current system of bi-monthly catch limits is replaced with IFQs.

In sum, the analysis of scale efficiency suggests fleet downsizing under the proposed IFQ management. As more catch is consolidated onto fewer vessels, average costs per landed pound of groundfish is expected to fall due both to increases in scale economies and a redistribution of the harvest from the least to the most efficient vessels in the fleet. The combined effect will be a reduction in the total costs incurred to harvest the target aggregate harvests, or alternatively an increase in the resource rents that is generated in the fishery.

3.2 Minimum cost of harvesting the 2004 groundfish catch

This section estimates the minimum cost of harvesting groundfish across different configurations of vessel capital. Our approach is to estimate the minimum efficient scale of production for six different vessel types. We then calculate the average harvesting costs when our representative vessels harvest this quantity of groundfish. The estimated costs are then compared with estimates of the actual costs incurred by sample vessels to obtain an estimate of the potential cost savings in the PCGF.

Table 4 considers six vessel length classes; 40, 50, 60, 70, 80 and 90 foot boats. We determine fuel carrying capacity for a vessel of length L as the average fuel capacity for vessels of similar length. For example, an $L=50$ foot vessel is assumed to be able to carry 2,587.6 gallons of fuel. This value is determined as the average fuel capacity for the 21 sample vessels with lengths ranging between

$L - 5$, and $L + 5$ feet in length (i.e., 45 and 55 feet). Column 1 in Table 4 reports the number of sample boats falling into each length class.

Column 4 of Table 4 reports estimates of the maximum annual pounds (a measure of physical harvesting capacity) for each vessel class. These estimates are obtained by examining the maximum landed pounds reported by each vessel category during 2003 and 2004, historical maximum landings by vessel class, and consultation with groundfish fishermen. A problem we face is that recent harvest activity data have been generated under bi-monthly landings restrictions under the Limited Entry management program. By design, regulations under Limited Entry management restrict per-vessel harvest which suggests that the annual landings reported in Table 3 in 2003 and 2004 will be low compared to the total landings under IFQs, i.e., when bi-monthly catch limits are eliminated. Historical data generated before bi-monthly limits could indicate the landings capacity under IFQ management. However, historical data will be conditional on stock conditions that prevailed in the fishery in past years. To circumvent this problem we consulted groundfish fishermen, and all available data to settle on the capacity estimates reported in Table 4. The sensitivity of the results to capacity constraint estimates is examined further below. Vessel Value and Maintenance and repair expenditures are reported in columns 5 and 6, respectively. Their derivation follows equations (4) and (3) as discussed above. Notice that estimates of Vessel Value indicate that 40 foot boats sell for \$188,634 whereas 50 foot boats sell for \$177,984. One would expect the relationship between vessel length and value to be monotonic. The violation of this relationship for 40 foot boats is likely due to estimation error caused by a low number of observations on smaller vessels. It should also be noted that the cost data include only four observations for vessels in excess of 85 feet in length. The results for the smallest and largest representative vessel classes should be viewed with this limitation in mind.

For each vessel length class we calculate the harvest quantity that minimizes ray average cost (RAC). Note that RAC depends on the mix of harvested species. PACFIN data indicate that the 2004 Limited Entry fleet harvested 197.691 million pounds of whiting, 23.246 million pounds of DTS species, 21.238 million pounds of non-DTS species, 8.018 million pounds of crab, 5.112 million pounds of shrimp and 1.457 million pounds of *other* species. Given our focus on non-whiting boats we posit a target harvest vector which includes no whiting but positive quantities of the remaining 5 species groups, where the mix is set equal to the fleet-wide mix for these species.

A final required assumption is the level of cost efficiency attained by representative vessels. To investigate the role of inefficiency we calculate the minimum efficient scale of production and corresponding RAC for the 25%, 50% and 75% percentile values reported in Table 3 above.

Table 5 reports the catch per vessel (total pounds of all species), and minimum RAC attained for $\hat{v} = E[v|v + \epsilon] = 0.077, 0.107, \text{ and } 0.138$. An asterisk associated with the catch per vessel estimate indicates that vessel's physical harvesting capacity constraint binds. In particular, for vessels 40

Length	$\hat{v} = 0.077$		$\hat{v} = 0.107$		$\hat{v} = 0.138$	
	Catch	RAC	Catch	RAC	Catch	RAC
40	500,000*	0.329	500,000*	0.332	500,000*	0.335
50	850,000*	0.252	850,000*	0.255	850,000*	0.259
60	1,361,900	0.256	1,352,100	0.260	1,342,200	0.265
70	1,363,900	0.310	1,354,100	0.316	1,344,200	0.322
80	1,368,700	0.390	1,358,900	0.397	1,348,900	0.405
90	1,381,200	0.460	1,371,300	0.468	1,361,100	0.477

Table 5: IFQ-Regime Harvest Levels and Ray Average Cost Estimates RAC - denotes ray average cost; * - indicates the catch is equal to the physical capacity constraint.

through 70 feet in length, RAC is lowest at the maximum physical harvest capacity, which suggests that RAC falls over the range of (assumed) feasible harvest quantities.

Consistent with the discussion above, the results in Table 5 show that the variation in cost efficiency, \hat{v} , has only small effects on the scale-efficient catch per vessel and RAC. Higher values of \hat{v} lowers total catch and raises RAC as required. Comparing vessel lengths, the results indicate that RAC is lowest for 50 foot vessels although the differences between 50 and 60 foot vessels is almost imperceptible. Results indicate that smaller (40 foot) vessels and larger (70-90 foot) vessels incur higher costs per harvested pound. The finding that larger vessels incur higher costs must be interpreted cautiously as the analysis in this section is static and does not consider value of harvesting *flexibility* offered by larger boats and which is important in an uncertain fishing environment. We come back to this issue below in Section 4.

We next calculate the potential fleetwide cost savings in the 2004 groundfish fishery. This calculation is made by computing the actual RAC using cost survey data and comparing this estimate to the predicted RACs reported in Table 5. Actual fleetwide costs in the 2004 PCGF are estimated as a catch-per-vessel weighted average of sample RAC. This calculation reveals that groundfish vessels incurred costs of \$0.657 per landed pound of groundfish. PACFIN data reveal that in 2004, 59.080 million pounds of DTS, Non-DTS, crab, shrimp, and other groundfish (whiting catch in 2004 is 195.08 million pounds) were landed. Extrapolating the sample RAC estimate to the 2004 groundfish catch yields a total cost estimate of \$38.789 million. At average dockside prices (also obtained from the PACFIN database), the fleetwide revenue was \$36.275 million indicating a *loss* of \$2.514 million. Note that this calculation assumes a 10% annual return to the vessel capital investment. If we lower the interest rate to 5% the results reveals that the groundfish fleet broke even in 2004. That is, dockside revenues were just offset by the fleet-wide total harvesting costs.

The RAC estimate obtained from the cost survey data is considerably higher than the minimum RACs reported in Table 5. Three key factors can explain this difference. First, the RAC cost

		Pred. Cost	Cost Savings		Fleet size
	Len.	\$ Mill.	\$ Mill.	% of Actual	# Boats
1	40	\$19.599	\$19.190	49.47	119
2	50	15.072	23.717	61.14	70
3	60	15.377	23.412	60.36	44
4	70	18.604	20.149	51.95	44
5	80	23.476	15.313	39.48	44
6	90	27.651	11.138	28.71	44

Table 6: Minimum Cost of Harvesting 2004 Groundfish Catch. Fleet size is calculated by dividing the 2004 Groundfish harvest by the RAC-minimizing harvest.

minimizing catch per vessel as predicted by our analysis is considerably larger than the actual catch per boat reported in the PACFIN database. PACFIN data indicate that in 2004 the average total harvest per vessel was 433,800 pounds (see table 1). Table 5 suggests that 50 and 60 foot vessels attain a minimum RAC at a harvest that is roughly two times larger for 50 foot boats and almost three times larger for 60 foot vessels. Increasing the catch per vessel will reduce fleet size and in turn reduce the total fixed costs incurred by the groundfish fleet. Second, the analysis reveals that some capital types incur higher costs per landed pound than others. Results suggest that vessels in the range of 50-60 feet in length attain the lowest RAC. Consolidating the fleet-wide groundfish harvest onto the most efficient vessels types will further reduce the cost per harvested pound of groundfish. A third source of cost saving arises in the form of a pure efficiency gains. Although our analysis reveals only modest cost efficiency is indicated in the sample data, further savings are expected as harvesting responsibilities gravitate to the *highliners* in the groundfish fleet.

Table 6 reports estimates of cost inefficiency in the current PCGF. We estimate the excess harvesting cost as the difference between the sample RAC of \$0.657 per landed pound and minimum RACs reported in Table 5 (an efficiency level of $\hat{v} = 0.107$ is assumed). Predicted costs, and cost savings are reported in 2004 dollars, and as a percentage and estimated costs incurred in the fishery in 2004. Lastly, we estimate the fleet sizes associated with each vessel length class and cost estimate. The results in Table 6 can be interpreted as follows. Consider the 40 foot representative vessel length. If the entire PCGF fleet were made up of 40 foot vessels the fleetwide costs are predicted to be \$19.599 million in 2004. This represents a cost saving predicted at \$19.190 million which represents 49.47% of costs that are estimated incurred in 2004. To harvest the entire 2004 catch (excluding whiting) with a fleet consisting entirely of 40 foot boats, 119 vessels would be utilized. Moving to larger vessels, the results indicate that the cost savings are largest for fleets consisting of 50 and 60 foot vessels. Cost savings under these vessel lengths are in the range of \$23 million or 60.36% of the actual 2004 costs. The number of vessels required to harvest the 2004 catch is estimated at 70 and 44 for the 50 and 60 foot length classes, respectively.

PACFIN data reveal that 117 non-whiting groundfish limited entry trawlers were active in 2004 (number excludes 26 vessels that targeted whiting). Correspondingly, the results in Table 6 indicate that considerable fleet downsizing is expected under IFQ management as vessels consolidate the harvest and exploit available economies of scale.

3.2.1 Sensitivity to model assumptions

A final consideration is the sensitivity of the results to model assumptions, particularly the assumptions for physical harvesting capacity. We repeat the analysis of this section under the assumption that physical harvesting capacity is 25% lower than reported in Table 4. The results indicate only small changes in the predicted costs savings (59.34%) under IFQs. Note that the results in Table 5 indicate that the physical capacity constraint does not bind for 60-90 foot length classes. Thus under a tightened physical capacity constraint, the model suggests an IFQ-regime fleet consisting of larger boats, however only slightly larger RAC (\$0.267) is predicted. Relaxing the physical capacity constraint also has small effects on predicted cost savings under IFQs. A 25% increase in the physical capacity constraints raises the cost savings estimate to 64.82% of actual 2004 costs. We note that the cost savings estimates increase by roughly 1.5% when \hat{v} is set to 0.078 and fall by roughly 0.5% when \hat{v} is set to 0.138.

A second factor that impacts the above results is the mix of groundfish species that is harvested by vessels. Larger vessels have larger per-trip hold capacities and are capable of fishing in more severe weather. While the above results suggest that larger boats incur higher costs per landed pound, they land more fish annually which can provide an economic advantage particularly in a fishery with varying annual harvest quotas. This advantage is demonstrated in Figure 2.

Figure 2 plots the variable cost surfaces for 60 and 70 foot vessels. The four panels show the relationship between the mix of DTS and Non-DTS species and the variable cost surfaces for 60 and 70 foot vessels. Beginning in the northwest panel (a) and rotating clockwise, the ratio of DTS to Non-DTS species in the harvest vector is increased from 3/1 down to 1/3. In other words, the proportion of Non-DTS species in the target harvest bundle is increasing as one moves clockwise from panel (a) through panel (d).

Consistent with the above results variable costs are lower on 60 foot vessels, until of course the total catch reaches the 60 foot vessel capacity constraint at 1.5 million pounds. Capacity harvest on 70 foot vessels is higher at 1.95 million pounds. The additional capacity on 70 foot vessels can be an advantage in instances where the manager announces a particularly large TAC, relatively to the total harvesting capacity of the active groundfish fleet. In this event, harvesting additional fish on 70 vessels, even if this means harvesting fish at higher variable costs, may be preferred to adding additional boats to the groundfish fleet. The downside is that cost can rise sharply at high harvest

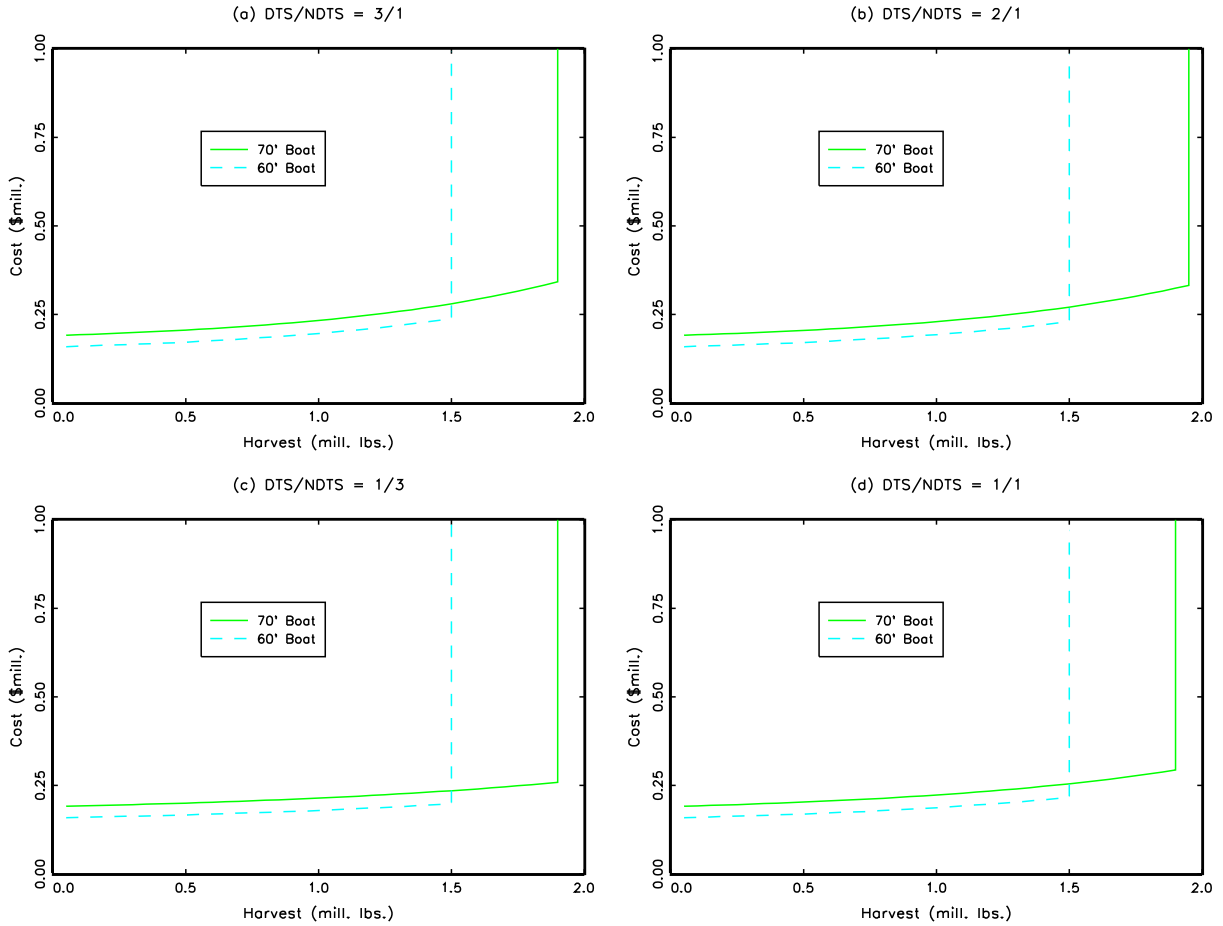


Figure 2: Cost, Capacity and Species mix.

levels which offsets the advantages offered by the additional physical capacity.

The figure demonstrates that the rate at which costs rise depends on the mix of targeted species. Recall from our estimation of variable harvest costs that, relative to non-DTS species ($\beta_{NDTS} = 0.5837$), DTS species not only have a higher marginal cost ($\beta_{DTS} = 1.2802$) for any given vessel type a fixed amount of harvest of all other species, but that these marginal costs increase more steeply than that of non-DTS species. As a result, when the ratio of DTS/Non-DTS is high as in panel (a) variable costs rise steeply offsetting the returns from utilizing large harvesting capacity. Put another way, when costs rise sharply average costs on larger capacity boats falls more slowly reducing the relative advantage of larger vessels. The Figure shows however that as the proportion of Non-DTS in the harvest mix increases, the cost surfaces flatten out. With a particularly high proportions on Non-DTS species in the harvest mix, the ray average cost on 70 foot vessels attains a lower value

than on 60 foot vessels. The upshot is that average costs per pound and value of harvesting flexibility offered on larger vessels will be more pronounced when the harvest mix is tilted toward non-DTS species.

4 Fleet Structure and Fishery Value Under IFQ Management

This section predicts the equilibrium fleet structure, harvesting costs and fishery rents that are expected to emerge under an IFQ management program. Based on the above analysis of the cost survey data, fleet size and costs are expected to decline. The magnitude of these changes will depend on the form that the IFQ program takes, e.g., the species that are included on the IFQ program and the restrictions, if any, that are placed on the transferability of harvesting permits. It will also be affected by TAC of fish that is announced by the fishery managers, and the randomness in the announced total allowable catches over time. This section first estimates a random harvest model which captures the randomness in TAC that is expected to prevail in the IFQ-managed fishery. We combine the harvest cost, and random harvest model into a dynamic model of the PCGF to estimate the fleet structure, harvesting costs, and rents expected under IFQ management.

4.1 Random harvest model

Growth, natural mortality and thus total stock abundance and allowable harvests are influenced by random fluctuations in the marine environment. Changing environmental conditions is likely to cause fluctuations in the TAC targets in the PCGF. Because variation in the TAC from year to year has implications for fleet size and fishing profits, we require a model that reflects the normal variability of these factors in the PCGF.⁸

We assume that the TAC of groundfish species m follows

$$(7) \quad Q'_m = z'_m \bar{Q}_m,$$

where \bar{Q}_m is the average TAC for species m and z'_m is a unit-mean multiplicative random shock. The random shock z'_m is contained in the interval, $[z_m, \bar{z}_m]$, where $z_m > 0$. Species-specific shocks follow a first-order autoregressive process,

$$(8) \quad z'_m = \varsigma_m + \rho_m z_m + v, \quad m = 1, \dots, M,$$

where $\rho_m \in [-1, 1]$, $\varsigma_m + \rho_m = 1$, and v is an independently and normally distributed disturbance with

⁸Data on abundance and growth characteristics for all groundfish species are not available. Consequently it is not possible to construct growth functions for all groundfish species and develop an optimal management model as in Singh et al. (2006).

zero mean and finite variance σ_z^2 . Hereafter, we refer to equations 7 and 8 as the *harvest transition model*.

To estimate the parameters of the harvest transition model we obtained annual landings data from the PACFIN data base for 1994-2006. Annual landings for the groundfish fleet in the PCGF for $m = 6$ species groups are shown in Figure 3.

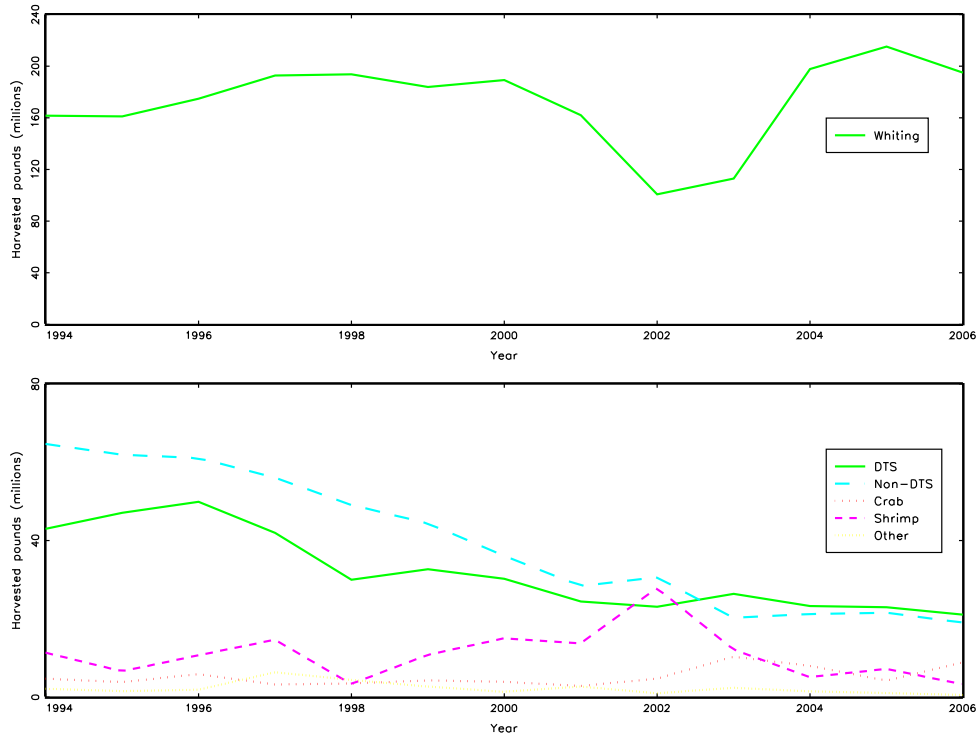


Figure 3: Whiting and Groundfish Landings: 1994-2006.

Visual inspection of historical landings indicates a declining catch for some groundfish species (e.g., DTS and non-DTS species groups). To ensure that catch trends do not influence the estimates of the harvest transition model, we assume the period t annual landings of species group m fish follows

$$\bar{Q}_{m,t} = a_m + b_m t.$$

The parameters of the model ς_m , ρ_m , a_m , b_m , $m = 1, \dots, M$ are estimated using feasible generalized non-linear least squares following Judge et al. 1985 (see p. 483-490).

Table 7 reports the parameter estimates along with the awc9406.epsdicted harvest for 2004. The estimate of $\sigma_z = 0.30$. We see that the harvest of each all species is positively serially correlated. It is also seen that the magnitudes of the ς_m and ρ_m do not much differ across species groups. We

Species	ς_m	ρ_m	Q_{2004}	\bar{Q}_{2004}
Whiting	0.49	0.51	197.69	178.98
DTS	0.53	0.47	23.25	24.23
Non-DTS	0.44	0.56	21.24	24.45
Crab	0.78	0.22	8.02	7.09
Shrimp	0.68	0.32	5.11	14.43
Other	0.74	0.26	1.46	1.43

Table 7: Harvest Transition Model: Parameter estimates Total 2004 harvest is millions of pounds.

estimated a restricted version of the shock transition equation in equation (8) in which $\varsigma_m = \varsigma$ and $\rho_m = \rho$ for all m . Based on the results of a likelihood ratio test, we failed to reject the null hypothesis that the random shocks follow a common process (the chi-square statistic is 0.071 with critical value 11.07). The results of the restricted model yield estimates of $\varsigma_m = 0.698$, $\rho_m = 0.303$ and $\sigma_z = 0.303$.

4.2 Dynamic Model of Fleet Structure and Fishery Rent

Our model of dynamic fleet adjustment closely follows Singh, Weninger, and Doyle (2006). The dynamic program is summarized by the following Bellman equation:

$$V(z, k_1, k_2, \dots, k_n) = \max_{\{k'_j, q_{ij}\}_{j \in \{1, 2, \dots, n\}, i \in \{1, 2, \dots, m\}}} \left\{ \begin{array}{l} \sum_{j=1}^n k_j (\sum_{i=1}^m p_i * q_{ij} - c_j (q_{1j}, q_{2j}, \dots, q_{mj})) \\ - \sum_{j=1}^n f c_j * k_j + \beta E \{ V(z', k'_1, k'_2, \dots, k'_n) \} + \sum_{j=1}^n p_{kj} i_j \end{array} \right\}$$

subject to $k'_j = (1 - \delta_j) k_j + i_j$,

and subject to equations (7) and (8). In the above functional equation, β is the inverse of the gross market interest rate; k_j denotes the number of vessels of class j ; q_{ij} denotes the quantity of species i harvested by a vessel of class j ; $f c_j$ is the fixed cost of a vessel of class j ; c_j is the per-vessel variable harvesting cost as estimated in (6); i_j is the number of new boats of class j inducted in the fleet and p_{kj} is its per unit price. Finally, E is an expectations operator.

Standard numerical techniques are employed to solve the above program by guessing an initial $V(\cdot)$ and then iterating it to convergence. The reader can refer to Singh, Weninger, and Doyle (2006) for technical details.

4.3 Results

This section presents the result from the dynamic model of the IFQ-managed groundfish fishery. We first examine fleet structure, costs and rents under a baseline scenario which imposes no restrictions on the transferability of the harvesting permits across vessels. We then consider the effects of: (1) a limit on the total quota that can be held (and fished) by individual vessels, and; (2) limits on harvest permit transferability across vessel classes.

The results that follow assume that active IFQ-regime vessels target groundfish species only.⁹ The added costs required to switch gear types and keep abreast of the most productive species-specific fishing sites can be avoided if vessels specialize in groundfish. Active IFQ-regime boats are expected to target groundfish species (DTS and Non-DTS species) and to harvest a small quantity of the Other species group as bycatch. Our baseline scenario assumes that the cost of moving a vessel in and out of the PCGF is 25% of the total vessel value. We assume that the market interest rate is 5%.

Low cost vessels will be able to profitably bid harvest permits away from higher cost operators. For this reason, the IFQ-regime fleet will favor mid-sized vessels 60-70 feet in length. However, this conclusion ignores idiosyncratic variation in harvesting performance that is likely to be a factor in the current groundfish fleet. Any vessel that can match the cost performance of the most efficient boats in the fleet will remain active. The results that follow, which assume fleets consisting of homogeneous “representative vessels”, should be interpreted with this caveat in mind.

Table 8 reports results for three different TAC scenarios. The first case assumes an average TAC equal to the total landed pounds in the 2004 PACFIN data (25.25 million pounds of DTS, 21.25 million pounds of Non-DTS and 1.46 million pounds of Other Species). The second case increases the TAC of DTS to 40.57 million pounds. The third case assumes annual average TACs for DTS and Non-DTS of 40.57 million pounds and 35.53 million pounds, respectively.

Our results reveal that 60 and 70 foot vessels operate jointly and generate the highest profit per landed pound of groundfish. This suggests that the IFQ-regime fleet will consist of vessels 60 to 70 feet in length, although other vessels capable of matching the cost efficiency attained by these vessels may also remain active under the IFQ management regime.

Recall that 70' vessels have a higher capacity (1.95 m pounds) than that of 60' vessels (1.5 m pounds). It follows from our earlier discussion (following Figure 2) that the cost efficiency of 70' vessel increases as the TAC % of non-DTS species increases. This explains why the fleet size of 70' boats is increasing in the relative (to DTS species) TAC of non-DTS species as reported in Table 8.

⁹Based on discussion with industry members, it is reasonable to assume that there are returns to specializing whiting, and returns to specializing in groundfish species. It is reasonable to assume that there are scope diseconomies in the harvest of both whiting and groundfish species. similar arguments hold for the harvest of shrimp and crab. These species are not harvested jointly with groundfish species, and are not included under the proposed IFQ plan.

Case 1: $\bar{Q}_{DTS} = 25.25, \bar{Q}_{NDTS} = 21.25$								
Fleet		Vessel Activity		% TAC Harvested		Permit Prices		Rent
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	λ_{DTS}	λ_{NDTS}	Rent/Yr
32.11	60	1.221	\$0.489	100%	94.3%	\$ 0.433	\$ 0.264	\$14.369
5.37	70	1.314	\$0.459					
Case 2: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 24.57$								
Fleet		Vessel Activity		% TAC Harvested		Permit Prices		Rent
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	λ_{DTS}	λ_{NDTS}	Rent/Yr
52	60	1.195	\$0.483	99.99%	93.3%	\$ 0.430	\$ 0.262	\$20.482
2.6	70	1.300	\$0.469					
Case 3: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 35.53$								
Fleet		Vessel Activity		% TAC Harvested		Permit Prices		Rent
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	λ_{DTS}	λ_{NDTS}	Rent/Yr
50	60	1.225	\$0.480	100%	94.5%	\$ 0.433	\$ 0.263	\$ 22.543
9.9	70	1.325	\$0.467					

Table 8: Fleet Size, Harvest Cost and Rent Under IFQs. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

Of course, when the TAC of all species is increased as in Case 3, the fleet size across all efficient boat classes increases.

The results suggest a switch from the current LE management program to IFQs could yield a significant increase in resource rents in the PCGF. For instance, the results of section 3 indicated that the 2004 groundfish catch generated zero resource rent. Instead, it could have yielded a substantial positive rent at \$14.369 million (see Table 8) in the form of fleet-wide cost savings.

4.3.1 Harvest Permit Trading Restrictions

Restrictions on the concentration of quota ownership, and/or restrictions on harvest permit trades across vessel classes are often incorporated into IFQ program design.¹⁰ These restrictions may address ancillary social objectives. However trading restrictions of any sort will reduce the rent that is generated in an IFQ-managed fishery. This section investigates the effects of two common forms of harvest permit trade restrictions, quota ownership caps and restrictions on permit trading across vessel classes.

Quota Ownership Caps Case 1 in Table 9 shows the effect of a 1% quota share ownership cap for $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 24.57$. The 1% cap restricts the total pounds that can be landed by active vessels, and effectively restricts the fleet size to be no less than 100 vessels. The results show

¹⁰See Pautzke and Oliver (1997) for a discussion of permit trading restrictions in the pacific halibut IFQ program.

Case 1: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 24.57$ with 1% Quota Ownership Cap							
Fleet		Vessel Activity		% TAC Harvested		Rent	
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	Rent/Yr	Rent loss
100	50	0.644	\$0.264	100%	94.4%	\$16.715	\$3.767

Case 2: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 35.53$ with 1% Quota Ownership Cap							
Fleet		Vessel Activity		% TAC Harvested		Rent	
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	Rent/Yr	Rent loss
99	50	0.705	\$0.279	100%	87.9%	\$18.649	\$3.876
1.5	60	0.771	\$0.283				

Table 9: Restrictions on Per-Vessel Quota Ownership. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

that the most preferred vessel length is now a 50 foot vessel, rather than 60 and 70 foot vessels as in the unrestricted case. Logically, 50 foot vessels have lower fixed operating costs and achieve a smaller average cost at the restricted catch levels that are implied by the 1% ownership cap. In addition to altering the preferred vessel length, the 1% quota ownership cap results in a loss of \$3.767 million (18.4%) in annual fishery rent. This is because the fleet is maintained at inefficiently large level, preventing the fleet from exploiting available economies of scale.

Case 2 of Table 9 maintains the 1% quota share ownership cap but assumes higher average TAC conditions in the fishery; $\bar{Q}_{DTS} = 40.57$, and $\bar{Q}_{NDTS} = 35.53$ (counterpart to Case 3 in Table 8). Interestingly, the equilibrium fleet is now comprised of a mix of 50 foot (99 on average) and 60 foot boats (1.5 on average). While tight quota caps favor smaller boats, larger average TACs leave some room for the use of cost efficient boats and thus 60' boats are back in use. The quota ownership cap places an artificial limit on the annual harvest for active vessels. The model shows that this causes fluctuations in fleet size that did not occur in the unrestricted fishery. These unnecessary adjustments in fleet size are costly and detract from the total rent generated in the fishery. The results find that relative to the unrestricted case, annual rents decline by \$3.876 million.

Permit Trading Restrictions Across Vessel Classes We next examine the effects of a restriction on permit trading across vessel classes. For example, the pacific halibut fishery IFQ program restricted quota share trades from smaller to larger vessel classes (trading in the opposite direction, i.e., from larger to smaller vessel classes was permitted).

The results in Table 10 are not surprising. In particular if 50% of the TAC must be harvested by 50 foot boats, 65 such boats are active in the fleet. Since the 50' fleet must have enough boats to harvest 50% even under maximum possible TAC, these boats on an average harvest more than 50% of the TAC. As a result, the optimal fleet size of 60' vessels falls from 52 (see Case 2 in Table 8) to 12.6. Overall the trading restriction reduces the rent in the fishery by \$2.136 million per year

Case 1: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 24.57, 50\%$ of Quota Allocated to 50' Boats							
Fleet		Vessel Activity		% TAC Harvested		Rent	
Boats	Len.	Catch/boat	Prof./boat	DTS	Non-DTS	Rent/Yr	Rent loss
65	50	0.753	\$0.329	99.97%	86.66%	\$18.346	\$2.136
12.6	60	1.050	\$0.340				

Case 2: $\bar{Q}_{DTS} = 40.57, \bar{Q}_{NDTS} = 35.53, 50\%$ of Quota Allocated to 50' Boats							
Fleet		Vessel Activity		% TAC Harvested		Rent	
Boats	Len.	Catch/boat	Prof./boat	DTS	Non-DTS	Rent/Yr	Rent loss
75	50	0.755	\$0.316	100%	88.78%	\$19.901	\$2.642
14.6	60	1.078	\$0.327				

Table 10: Permit Trading Restrictions Across Vessel Classes. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

(10.4%). The results for Case 2 which allocates 50% of now a larger TAC to 50' boats increases the number of these vessels even further, and causes further reductions in the fishery rent.

4.3.2 Observer costs, landing taxes, and optimal fleet size

Here we examine the impact of landing taxes that may be needed to support the observer programs. We first consider a tax that is levied equally on all boats on a per day (at sea) basis. It is assumed that an observer costs \$350 per day. The results that follow are based on the following rough estimates of how many days per year a boat will be at sea when employed to its full capacity:

Length (ft.)	40	50	60	70	80	90
Full capacity days at sea	100	130	150	160	170	170

Based on the above estimates, Table 11 shows how a tax of \$350 per day at sea impacts the optimal fleet size, and their respective harvest levels.

A uniform per day tax on all vessels tilts the optimal fleet size towards bigger vessels, simply because on a per pound of catch basis the tax on harvests by bigger capacity boats is smaller. As is evident, while in the no-tax case the average fleet size of 60' and 70' vessels are respectively about 51 and 2.5, with taxes the new numbers are 31 and 18. Also notice that not only a higher number of 70' vessels are hired, but their mean catch levels also rise, while that of 60' vessels instead decline. As a result, the profitability (net of observer costs) of 70' vessel increases, while that of 60' vessels declines.

For the two cases under consideration, Table 12 shows that the %TAC harvested is almost unaffected. Clearly, as a part of the rent must go towards paying taxes, the lease prices of both species is now smaller. However, the lease price of non-DTS species drops less since taxes favor higher catch boats which are relatively more efficient in harvesting non-DTS species.

Case 1: No observers						
Fleet		Vessel Activity			Rent	
Boats	Len.	Catch/Bt.	Prof./Bt.		Rent/Yr	
50.97	60	1.195	\$0.483		\$20.482	
2.62	70	1.300	\$0.469			
Case 2: With observers						
Fleet		Vessel Activity			Rent	
Boats	Len.	Catch/Bt.	Prof./Bt	Obs.Cost/Bt.	Rent loss	Tax Rev.
31.42	60	1.127	\$0.472	\$0.039	\$2.203	\$2.065
17.57	70	1.682	\$0.502	\$0.048		

Table 11: Implications of Landing Taxes to Fund Observers. TACs are set at $\bar{Q}_{DTS} = 40.57$ and $\bar{Q}_{NDTS} = 24.57$. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

Case 1: No observers			
% TAC Harvested		Permit Prices	
DTS	Non-DTS	λ_{DTS}	λ_{NDTS}
99.99%	93.3%	0.43	0.262
Case 2: With observers			
% TAC Harvested		Permit Prices	
DTS	Non-DTS	λ_{DTS}	λ_{NDTS}
99.97%	93.2%	0.416	0.256

Table 12: Implications of landing taxes to fund observers. TACs are set at $\bar{Q}_{DTS} = 40.57$ and $\bar{Q}_{NDTS} = 24.57$. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

Case 1: With landing tax of 3.25 cents per lb.							
Fleet		Vessel Activity		%TAC Harvested		Rent	
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	Rent loss	Tax Rev.
42.26	60	1.254	\$0.475	99.98%	89.59%	\$2.219	\$2.045
7.13	70	1.388	\$0.450				

Case 2: With an ad-valorem tax of 7%							
Fleet		Vessel Activity		%TAC Harvested		Rent	
Boats	Len.	Catch/Bt.	Prof./Bt.	DTS	Non-DTS	Rent loss	Tax Rev.
42.26	60	1.243	\$0.470	99.98%	90.93%	\$2.201	\$2.052
7.91	70	1.377	\$0.451				

Table 13: Implications of Landing Taxes to Fund Observers. TACs are set at $\bar{Q}_{DTS} = 40.57$ and $\bar{Q}_{NDTS} = 24.57$. Boats are annual averages. Catch/Bt. and Prof./Bt. is in millions of pounds and millions of \$2004 dollars, respectively. Lease prices are in \$2004. Rent/Yr is in millions of \$2004.

The rent loss of \$2.203 million (about 11%) includes losses due to (a) the payments to observers and (b) distortion generated by the taxes. The mean of total observer payments are calculated to be \$2.065 million, and therefore the loss due to distortions amounts to \$0.137 million per year. Note that our model does not consider any benefits provided by the observers; calculated losses are likely to be smaller or even turn into net benefits if the benefits provided by the observers is taken into account.

We next consider two alternative ways to raise funds for supporting observer programs. The first is a per pound landings tax of 3.25 cents, while the second is an ad-valorem landing tax of 7% on the dockside price. These taxes/rates have been roughly estimated from the total observer costs and the landings obtained under the per-boat tax case presented above in Table 11.

The two tax schemes yield almost identical outcomes in terms of their effect on the optimal fleet size. Relative to per-vessel observer taxes, the boats employed now are closer to the no-tax scenario (see Table 11). However, taxes still favor larger vessels. Why? Notice that 60' vessels operate relatively closer to capacity in comparison with larger vessels. Since taxes are based on harvest quantities, the relative benefits of 60' vessels decreases.

It is also worth noting that while the %TAC harvest of DTS species is unchanged relative to the no-tax case (as well under per-boat taxes), the %TAC harvest of non-DTS species declines by almost 4% (1.5%) under per pound (ad-valorem) taxes. The reason is simple. A landing tax of 3.25 cent per pound decreases the effective price of DTS species by about 6.5% whereas for non-DTS species the decline is about 11%. Ad-valorem taxes affect all effective prices in the same proportion. However, to the extent that the TAC of non-DTS species were not being harvested fully even with no-taxes, a lower effective price depresses its harvest even further.

Notice that the rent losses and taxes collected under the two alternative tax schemes as shown

in Table 13 closely match that under per-boat taxes (see Table 11). However, after subtracting tax revenues the losses solely due to tax distortions amount to \$0.175 million and \$0.149 million under per pound and ad-valorem landing taxes, respectively. A relatively higher loss under the per-pound landing tax is due to its distortionary effect on the relative prices. Notice further that both of these losses exceed that incurred under per-boat taxes (\$0.137 million).

5 Conclusion

This paper examines the economic implications of adopting an individual fishing quota (IFQ) management program for pacific coast limited entry trawl non-whiting groundfish. The conceptual approach follows recent work by Weninger and Waters (2003) and Singh et al. (2006). We first estimate the vessel-level costs which are then utilized within a dynamic optimizing framework to make policy predictions.

Our results suggest that the current limited entry trawl groundfish fleet which consisted of 117 vessels in 2004-05 will be reduced by to roughly 50 - 66% to 40-60 vessels under an IFQ program. The significant reduction in fleet size will result in costs savings in the fishery in the range of \$18 - \$22 million annually (all values are in \$2004). Vessels that remain active will on average be more cost efficient and will benefit from economies of scale that are currently unexploited in the fishery. The cost savings estimates are significant amounting to roughly 60% of costs incurred currently, suggesting that IFQ management may be an attractive option for the PCGF.

However, if the IFQ program design places additional restrictions on permit trading, such as caps on vessel level harvests, or restrictions on permit trading across vessel classes, the cost savings will be lower. In general, tight harvest quota ownership caps for individual vessels will favor smaller boats due to their lower fixed costs. Restrictions on permit trading across vessel classes will keep vessels active that would otherwise exit the fishery. Both forms of trading restrictions will reduce rents that are generated under the IFQ program.

We have also examined the implications of “days-at-sea” and landing taxes for the optimal fleet size as well as harvest outputs. In general, both taxes favor larger vessels. While days-at-sea taxes only distort the optimal mix of the active fleet, landing taxes by affecting relative dockside prices distort both the fleet structure as well as the harvest quantities. As a result, net of tax revenues, losses under landing taxes are higher.

6 References

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7 Appendix A: Regulations and Fishery Resource Rents

This section will discuss economic conditions that have led to the current biological, economic and regulatory conditions in the PCGF. The goal is to provide background to understand the changes that are expected to occur in the PCGF under an IFQ management program. We begin by discussing the concept of fishery resource rent and rent dissipation due to ill-defined property rights in fisheries.

Fisheries resource rent is pure profit, broadly defined, that natural resources such as ocean fisheries are capable of providing to society.¹¹ Resource rent associated with groundfish consumption is given as the surplus value that is derived from the harvest of PCGF. People enjoy and are willing to pay money to consume groundfish in their diets. The market price for groundfish is a measure of the value, per unit of fish, that society places on consumption. Factors of production that are used up in the process of harvesting groundfish, e.g., vessel capital services, captain and crew labor, fuel, bait and ice are must be forfeited before groundfish can be consumed. These factors could be allocated to other productive uses in the economy and thus their allocation to the groundfish fishery represents a cost to society. The difference between the value that society places on harvested groundfish and the value of the productive factors that must be given up in harvesting operations is the *resource rent* that is generated in the fishery

Resource rent can be significant in ocean commercial fisheries. This is because natural processes take care of a significant component of the *production* of fish. While ocean fisheries have the potential to generate resource rents, it has long been recognized that the rents tend to be dissipated if fisheries are unmanaged or poorly managed (Gordon, 1954). Munro and Scott (1996) classify two ways in which fishery rents can be dissipated the Class I and the Class II common property problem. We discuss these two forms of rent dissipation is seriatim.

Fish stocks are a renewable resource that exhibit density dependent growth: the quantity of fish available for future harvest depends on the quantity of fish remains in the sea to reproduce and grow. Rents can be dissipated over time when no single individual owns the fishery resource. The reason is that any conservation effort that is undertaken currently, for example stock conservation by an individual fishermen, must be shared by other individuals who participate in the fishery. If the number of participants is large, which is often the case, the future benefit that the individual receives from his/her conservation effort today is imperceptible. Because conservation benefits are shared, too little conservation is an undertaken. Fishery rents are dissipated as the stock is fished below the level that yields the largest per period profit on a sustained basis.

Preventing Class I rent dissipation is the main objectives of most fisheries management programs, and is a major goal of managers in the PCGF. Current management in the PCGF uses restrictions on

¹¹To simplify the discussion that follows we will focus attention on the resource rent that is generated from the human consumption of groundfish.

fishing activities to limit the annual harvest of groundfish, or in other words, to prevent overfishing due to the Class I common property problem. Managers set target catch rates, which have been deemed optimum yield¹² for most groundfish species. Regulations such as catch limits, closed areas and gear restrictions are used to ensure that the total catch does not exceed the target.

Protecting the fish stock from overharvest does not alone however prevent resource rent dissipation. The second source of rent dissipation, the Class II common property problem occurs when too many factors of production are used to harvest the target groundfish catch. The problem is that controlled access management does not address the incentive to dissipate resource rents. In fact controlled access creates an environment where the incentives of fishermen are directly opposed with the goal of resource rent preservation. The source of the misaligned incentives lies in the nature of the property right that is granted to fishermen under command and control regulation.

Page 129 of the FMP states: *Groundfish LE permits and endorsements confer a right to participate in the West Coast groundfish fishery with an limited entry gear in accordance with the limited entry system established under the groundfish FMP as modified by this chapter of the FMP (created under Amendment 6) or any future amendment which may modify or even abolish the limited entry system.*

The key term is “right to participate” which is essentially a right to compete with other LE permit holders for a share of the available resources. In a LE-managed fishery resource rent is secured by an individual fishermen at the point that the fish is landed on the deck of the boat. As long as the *unit* resource rent is positive, participants in the LE fishery have an incentive to increase their share of the total groundfish harvest. Only when the unit rent is zero does this incentive disappear.¹³

Precisely how are resource rents dissipated under LE management? The answer becomes clear by realizing that in order to address the Class I common property problem, the total harvest of groundfish must be capped. Suppose the fleetwide harvest level is at the target or optimum yield that has been chosen by the fishery manager. Suppose now that a single fishermen makes an adjustment to his/her vessel or gear with the goal of increasing the vessel’s catch. This strategy may raise profits for example if unit resource rent is positive, in other words if the revenue received for the additional catch exceeds the cost of the vessel and gear adjustments that are undertaken by the fishermen. One of two things must happen in response to an increased catch by this fisherman: (1) the manager must tighten the restrictions on harvesting practices to maintain the total catch at the target optimum yield, or (2) the share of the total catch for some other fishermen in the fleet must decline.

While the actions taken by a single fisherman to increase the share of the total catch may seem

¹²Page 9 of the FMP provides the following definition: “Optimum yield means the amount of fish which will provide the greatest overall benefit to the U.S., particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems, is prescribed as such on the basis of the maximum sustainable yield from the fishery as reduced by any relevant economic, social, or ecological factor; and in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery.”

¹³Terms such as the *race for fish* and *capital stuffing* have emerged in the fisheries management literature to describe the process by which individual fishermen modify their fishing practices to secure larger shares of the available catch.

imperceptible, it is important to realize that all fishery participants face the same incentive. As long as unit resource rent is positive each participant has an incentive to allocate additional capital, labor and energy in an attempt to increase their individual share of the available harvest, or available resource rent. Perhaps a more apt term for this phenomenon is a *race for resource rent*.

The most likely response to a catch-share-increasing investment by fishermen is a tightening of the gear or seasonal restrictions on harvesting. This can only imply increased harvesting costs per unit of fish. Since the manager is committed to addressing the Class I problem, the target catch, and thus the total value of harvest fish, is unchanged. The Class II common problem results because tighter restrictions on harvesting activities raise the costs of all vessels in the fleet (see Weninger and McConnell, 2000, for additional discussion).

7.1 How does IFQ management address the Class I and Class II common property problems?

The fundamental difference between IFQs and controlled access management such as the LE program in the PCGF is the point at which fishery resource rents is secured. IFQ harvest shares grant their owner a right to harvest a specific quantity of groundfish each year. Under this system, the Class I problem, i.e., controlling the total groundfish harvest is addressed with an *output* control rather than a control (i.e., restrictions) on the *inputs* that are allocated to the fishery. The Class I problem is addressed by issuing in each period harvest permits that sum to the optimum yield in the fishery.

Next consider the Class II problem under IFQ management. A simple example will be used to illustrate the economic incentives faced by quota owners. Suppose that a fisherman owns IFQ shares that grant the right to harvest 100 units of fish in the current period. Productive inputs must be allocated to harvest the fish. The catch is then sold at the dock. Importantly, the fisherman is the residual claimant of any profits that are made from harvesting the 100 units of fish. Suppose that after the fish is caught and sold, and all harvesting expenses including a fair return to the time spent operating the boat, are tallied, the fisherman is left with \$100. This \$100 is the resource rent that is earned by this particular fisherman. The rent per unit of the catch is \$1.

The Class II problem is addressed under this system because harvesting rights are tradable, and as such will gravitate into the hands of those who can earn the largest residual profit from fishing. If there is some other fisherman who can earn more than \$1 per unit of fish, this individual can profitably purchase IFQ shares from the fisherman who earns only a \$1. The incentive under the IFQ system is not to increase their share of the total catch, but rather to increase the residual profit that can be earned from harvesting the fish associated with IFQ shares.

More generally, there will exist an incentive to trade IFQ shares whenever gains from trade are available. Some fisherman may be able to catch fish at a lower cost than others simply because they employ a better crew, or have better information about where and when to catch groundfish. These

fishermen will be able to bid IFQ shares away from higher cost fishermen. Alternatively, costs per harvested pound may be lower if vessels take more trips and harvest more groundfish in a season. Any permit trades or fleet adjustment that lower the cost of harvesting groundfish will increase the value of the IFQ shares. This is precisely what is required to address the Class II common property problem in the fishery.

7.2 Fleet structure and resource rent under LE management

We will assume that the population of vessels that are capable of participating in the fishery is large. A subset of these vessels will be active in the fishery at each point in time, where *active* will be defined by the requirement that the vessel lands a positive quantity of at least one fish species during the production period.

Suppose N^{LE} limited entry permits are issued by the management authority. The number of active vessel operations cannot exceed N^{LE} . Suppose that in addition to limiting the number of participating vessels, restrictions on harvesting activities are required to ensure that total fleet harvest does not exceed the total harvest target Q . In this environment, the cost of being active, i.e., harvesting fish under the LE-management program involves two opportunity costs. The first is cost of the vessel capital, ψ_k . The second is the cost of owning a LE permit. Excess operating profits under LE management will be capitalized into the price of the entry permit, and will be determined by the present value of the stream of profits that a non-permit holder could earn in the LE-managed fishery. The criterion for being active under LE management can thus be written as

$$\pi_k^{LE}(q, X) \geq \psi_k + \rho\lambda^{LE},$$

where ρ is a risk-adjusted interest rate, and λ^{LE} is the perpetual ownership price for the LE permit. The notation π_k^{LE} is used to emphasize that per-period variable profits are impacted by the harvesting restrictions that are imposed under LE to ensure that the aggregate harvest does not exceed the target Q .

The equilibrium price of the LE permit will be determined by entry-exit decisions of the population of vessel operations. Suppose that operating profit and thus resource rent in the fishery is positive. In this case more vessels would enter the fishery if additional permits were available. Since the number of permits is fixed however, entry can occur only if a non-permit holder purchases a permit from an active vessel. In equilibrium no vessel should be able to profitably enter or exit the LE-managed fishery. The permit price will be determined by the value that the most skilled non-permit holder places on its ownership. More formally, rank the population of vessel operations from lowest to highest cost. Let \tilde{k} denote the skill level of the $N^{LE} + 1$ ranked vessel operation. In an entry-exit equilibrium, the first N^{LE} boats will own an LE permit, and the permit price is

determined as,

$$\lambda^{LE} = \frac{\pi_k^{LE}(q, X) - \psi_k}{\rho}.$$

The factors influencing λ^{LE} include the number of permits issued, restrictions used to prevent overfishing since these restrictions impact harvesting profits, the cost of vessel capital, stock abundance, dockside prices and the required rate of return on fishing capital. As argued in the previous section, fisheries managers may be forced over time to impose increasingly stringent restrictions on the harvesting activities of vessels to prevent overfishing. These restrictions raise cost, and lower operating profits, which ultimately drive rents and entry permit prices to zero.

Note however that resource rent dissipation does not address the misaligned incentives for active fishermen in the LE-managed fishery. The term *latent effort* has been used to describe situations where the number of LE permits exceeds the number of active vessel operations. This phenomenon is understood by considering differences in cost efficiency across vessels. As harvester operating rules are tightened to protect fish stocks, variable profits of the most efficient vessel operation can remain above the opportunity cost of capital, while other less efficient operators exit the fishery.

In sum, LE management does not align the fleet size, i.e. active vessel operations, with the target catch in a way that is capable of minimizing harvesting cost (or maximizing resource rent). In practice, the number of entry permits issued by the management authority is arbitrary; typically determined as the number of boats active in the fishery when the LE program is introduced. Resource rents can be positive but are in all likelihood reduced through the Class II common property problem. When rents are fully dissipated, the number of active boats is determined by a zero profit condition, $\pi_k^{LE}(q + d, X) = \psi_k$, which implies $\lambda^{LE} = 0$.