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Planning Models for Individual Transferable Quota Programs[1]

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This paper develops an approach to simulating markets for individual transferable quotas prior to their actual implementation. This approach is based on linear programming models for individual vessels that allow estimation of market derived demand for quota to simulate the expected equilibrium market price for quota and maximum quasi-rents for alternative quota allocations. The simulated price is an annual lease or rental price. The approach, applied to a sample of longline vessels targeting sablefish (*Anoplopoma fimbria*) in the Columbia INPFC area of the United States, indicates substantial potential gain in quasi-rent and economic efficiency from quota trade. The simulated quota exchange also indicates potential for concentration of quota. The quota market risks becoming thin, noisy, and hampered by noncompetitive forces, potentially requiring limits to quota transfer and concentration.

Le présent article élabore une approche pour la simulation des marchés des quotas individuels transférables avant leur mise en oeuvre réelle. L'approche est basée sur des modèles de programmation linéaire pour les navires individuels qui permettent d'estimer la demande du marché en quotas afin de simuler le prix d'équilibre du marché prévu pour le quota et les quasi-rentes maximales pour les autres allocations de quotas possibles. Le prix simulé est un prix de crédit-bail ou de location annuel. L'approche, appliquée à un échantillon de palangriers pêchant la morue charbonnière (*Anoplopoma fimbria*) dans le secteur INPFC Columbia aux États-Unis, indique un gain potentiel substantiel en matière de quasi-rentes et d'efficacité économique découlant du commerce des quotas. La simulation des échanges de quotas indique également un potentiel de concentration des quotas. Le marché des quotas risque de devenir faible, tumultueux et entravé par des forces non concurrentielles, ce qui pourrait nécessiter l'imposition de limites au transfert et à la concentration des quotas.

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1. Introduction

Individual transferable quotas (ITQs) are tradable property rights over the flow of the resource stock (Scott 1986). Each vessel is allocated a quantity of the total harvest for which it has a right to catch over some time period. ITQs are now earning the attention of fishery managers worldwide as a means to regulate common property fishing industries (Muse and Schelle 1989).

Several fundamental issues concern regulators and industry when planning or considering the feasibility of an ITQ program. First is the expected equilibrium price and economic rents (total revenue less the payment required to bring into production an input fixed in supply). A second concern is the gains in economic efficiency from quota trade.[3] Third, regulators are concerned about potential quota and industry concentration and competitiveness as well as thinness (number of participants) of the quota market. Resolution of these sources of uncertainty would enable better evaluation and planning of prospective ITQ programs.

This paper is expository, with several purposes. First, the paper aims to facilitate transfer of information from economics to fisheries management. Second, the paper develops a simulation model of an ITQ market based on linear programming models for individual vessels that can address the above concerns about a proposed ITQ program while it is still in the planning stages. Third, the simulation model estimates economic benefits from a potential ITQ program in a longline fishery for sablefish (*Anoplopoma fimbria*) off Oregon and Washington in the United States and estimates the expected price of quotas for alternative allocations among vessels. The efficiency gains from quota trade and expected equilibrium ITQ price from the simulation model are short-run, since they are conditional upon the existing vessels; Squires et al. (1992) addressed the expected entry/exit of vessels and industry structure of the fleet. The simulated price is an annual lease or rental price.

The paper proceeds as follows. Section two discusses important features of an economic model of ITQs and a survey of the relevant modeling literature, ITQ price formation, background information on the longline fishery for sablefish, a linear programming model to estimate the vessel's short-run production technology and unit quota rents, which form the basis of the simulation, and short-run equilibrium price formation of the ITQ and expected quasi-rents and gains from trade. Section three reports empirical results from the simulation model and discusses policy implications for an ITQ management program.

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[3]Gains from trade, i.e. arbitrage efficiency, due to production are the increase in value of output (producer surplus) that occurs due to trade between producers. This exchange allows producers to specialize according to their comparative efficiencies. Gains from trade can also include consumption gains (consumer surplus). Only producer gains are considered because output prices are assumed constant in this paper.

2. Materials and Methods

2.1. Features of an Economic Model for ITQs and Literature Review

The economic model of ITQs rests upon the foundation initially developed in the environmental pollution (Dales 1968; Baumol and Oates 1971; Montgomery 1972; Weitzman 1974) and international trade (Anderson 1988) literatures and extended by Christy (1973) and Moloney and Pearse (1979) to fisheries. This framework builds upon the individual firm (vessel), explicitly recognizing that the market for ITQs is formed by individual firms exchanging quota. This paper uses firm and vessel interchangeably but recognizes that some firms may be multivessel.

The fisheries literature on ITQs (Christy 1973; Moloney and Pearse 1979; Copes 1986; Scott 1986; Lindner et al. 1989; Muse and Schelle 1989; Sissenwine and Pace 1992) has not fully recognized two other important points. The first (Lau 1976) recognizes that the vessel's (firm's) production decisions are made in two steps. In the first step, the vessel maximizes profits (total revenue less operating costs) in the short term from the existing capital stock (vessel and equipment). (These short-run profits are also called quasi-rents or producer surplus; see Just et al. 1982.) In the second step, the vessel adjusts, over a longer time period, its capital stock (e.g. change vessels) to the appropriate size to maximize long-run profits.

The second point (Schulze and d'Arge 1974) is that both short- and long-run economic efficiency have two requirements when controlling an externality (a cost external to the vessel but which affects other vessels in the fishery, such as the abundance of fish in open-access fisheries). The first requirement is that the marginal value of the vessel's output must equal marginal cost (both internal and external to the vessel). The second requirement is that the total value of the vessel's output must not be less than total costs (both internal and external to the vessel).

Taken together, these points imply that a single, long-run equilibrium ITQ price does not immediately develop. Instead, equilibrium ITQ prices form over short-run periods as individual vessels exchange quota. Over a longer time period, vessels evaluate all revenues and costs, including the expected ITQ price and their implicit marginal valuation of their capital stock, and then adjust their capital stock or technology by changing vessel size, gear, or electronics, or by leaving the industry. New participants may also enter the industry. Although beyond the scope of this paper, it is also possible that changes in industry structure may change fish stock biomass and production costs, which will induce additional changes in the industry.

An ITQ price subsequently forms for the corresponding long-run equilibrium structure of the fleet. This price includes the user cost of the unpriced resource given the existing fleet size and structure and an optimally set quota (Moloney and Pearse 1979). The user cost of the resource is the opportunity cost to the user of taking a unit of the resource in the present period and represents the shadow price of the fish stock (Clark 1976). This long-run price is the present value of the net returns from this asset.

The vessel's investment and entry/exit decision and long-term ITQ price formation can take varied lengths of time. In the Australian bluefin tuna (*Thunnus thynnus*) and U.S. surf clam (*Spisula solidissima*) fisheries, industry restructuring proceeded fairly rapidly, while the process has been protracted in New Zealand (Geen and Nayer 1989; Lindner et al. 1989; Campbell 1990; Anonymous 1991).

In sum, economic models of ITQs should recognize that ITQ markets are formed by individual vessels (firms) exchanging quota and that different ITQ prices exist for different periods.

The issue of competitive equilibrium market prices must also be addressed by simulation models of ITQ markets. Hahn (1984) and Misiolek and Elder (1989) examined non-competitiveness or monopoly power in the market for tradable property rights over pollution, and Anderson (1991) extended the analysis to fisheries. When simulating the initial, short-run ITQ price for the existing fleet, lack of market competitiveness from a small number of participants may not necessarily pose a problem, since quota is typically allocated amongst an overcapitalized fleet with excessive vessel numbers. Also, evaluating the vessels' investment and entry/exit decisions and likelihood for quota trade sheds light upon this issue.

The paper's simulation generates a single competitive equilibrium price for ITQs, but in practice one may not form. Lindner et al. (1989) and Lindner (1990) found evidence of considerable price dispersion (widely distributed prices rather than a single equilibrium price) and sequential, bilateral exchange in New Zealand. Nonetheless, simulating the expected equilibrium ITQ price for the existing fleet provides the best possible estimate of the expected price and also a basis for comparing alternative policies.

Empirical studies of ITQs in fisheries have only recently emerged. Geen and Nayer (1989) assessed ITQs in a retrospective or ex post framework for the Australian bluefin tuna. Their industry-wide bioeconomic model generated the long-run equilibrium price of quota and industry structure. Geen et al. (1990) applied linear programming to assess a priori a program of individual quotas in the multispecies southeast trawl fishery in Australia. Individual quotas could not be explicitly transferred in the model and the effects of quota trading on adjustments in production were incorporated into the model indirectly. Hence, this model primarily focused upon the long-run effects of investment and industry restructuring under ITQs. Haynes and Pascoe (1988), in a linear programming study of the northern prawn (*Pandalus borealis*) fishery of Australia, noted that the results of an industry-level model correspond to a sole owner (solving the incomplete property rights structure of a common property fishery, thereby alleviating the stock effect externality) and hence give a theoretically identical result to that from a program of ITQs. This approach, while theoretically correct, assumes a common, single (aggregate) production technology for each vessel grouping. Most importantly, this approach does not allow fully analyzing the likely operation of the ITQ market to assess the hypothetical competitive equilibrium market price, resource rents (total revenue less costs), gains in efficiency from trade, and distribution of the licenses and trade patterns.

Squires (1990, 1991), following the two-step procedure above, simulated a potential ITQ program for trawlers. The expected short-run equilibrium ITQ price was estimated and the effect of the ITQ price upon the individual vessel's investment or disinvestment decision assessed. Econometric studies, such as this one, suffer from the possible failure of the model to be well behaved and from its parametric form, i.e. an explicit functional form must be imposed on the data. The econometric approach can handle statistical noise, but it imposes an explicit and possibly overly restrictive functional form for the production technology.

An alternative vessel-level approach is possible, drawing from the study of production efficiency in the economics literature (Lovell and Schmidt 1988). One strand of this literature circumvents the parametric assumptions of the econometric approach by representing each individual firm's production as a separate linear programming problem. Hence, studies of prospective ITQ markets can specify a linear program for each vessel, impose quota and calculate the unit quota rent, use this price (unit rent) – quantity relationship to simulate the ITQ market, and determine the ITQ's expected equilibrium price. This study develops this framework in a prototype procedure, adapting the empirical approaches of Hahn and Noll (1983), Anderson (1988), and Squires (1991) to linear programming to give the expected annual lease or rental price under certainty.

The deterministic qualities of the linear programming approach circumvent many econometric problems, but linear programming has limitations of its own. Linear programming imposes constant returns to scale (a 1% increase in inputs increases output by 1%), fixed proportions among outputs (Leontief technology), and nonjointness-in-inputs (separate production processes for each output or groups of outputs). Moreover, because of the linearity, profitable activities are employed subject solely to resource constraints rather than diminishing returns (e.g. rising operating costs as search time increases) and changing prices. Hence: (1) calibration of the model to observed production is difficult without adding a number of additional, ad hoc constraints and (2) large changes in the solution (basis) are often observed for small changes in the constraints, prices, or technical coefficients.

Other linear programming studies of fisheries include Brown et al. (1979), Siegel et al. (1979), Meuriot and Gates (1983), Overholtz (1985), Huppert and Squires (1987), Haynes and Pascoe (1988), and Geen et al. (1990).

2.2. ITQ Price Formation

After the allocation of quota but prior to its exchange, each unit (e.g. pound, percentage) of the quota has an implicit economic value or unit economic rent. For the profit-maximizing vessel, this unit rent τ, is the vessel's unit quasi-rent (producer surplus). That is, τ is the difference between the marginal revenue from production P (the increase in total revenue for a one-unit increase in output) and the vessel's marginal cost (MC, the increase in cost for a one-unit increase in output), i.e. $\tau = P - \text{MC}$. (With joint production, the quota's virtual price replaces marginal cost (Squires and Kirkley 1991). Virtual prices are those prices which would induce an unconstrained firm to behave in the same manner as when faced with a given vector of quantity constraints; see Neary and Roberts (1980) for further discussion.)

For a single year, τ is conditional upon the capital stock (vessel and equipment) and short-run marginal costs and is equivalent to the price of annual lease or rental quota measured as a quasi-rent (Campbell 1990). Over a longer period, when capital (vessel, equipment) has time to adjust, τ becomes the net present value of the expected net earnings stream, i.e. $\tau = \Sigma_t (P_t - \text{LMC}_t)/(1 + \delta)^t$, where δ is the discount rate, $t = 1, \ldots, T$, T is the planning horizon, LMC_t is expected long-run marginal cost (marginal cost when all inputs can vary) in time t, and P_t is the expected output price in time t.

This unit quota rent τ varies among firms according to the output and input prices they face and their marginal costs (which are determined by their production technology and prices for inputs such as fuel and labor). The important point here is that for exogenous and fixed output prices, the most efficient vessel (with lowest marginal costs) will place a higher value on a unit of quota than an inefficient one, i.e. $\tau_n > \tau_m$ because $\text{MC}_n < \text{MC}_m$. Consequently, a vessel n will demand quota from (supply to) firm m when $\tau_n > (<) \tau_m$. While the price paid for these species is constant and determined exogenously, MC varies with the level of quota held, so that quota purchase (sale) monotonically lowers (raises) τ in the quota market until an equilibrium market price for quota τ^* is formed and the value of a unit quota is the same for all vessels ($\tau_n = \tau_m$) at the last unit exchanged.

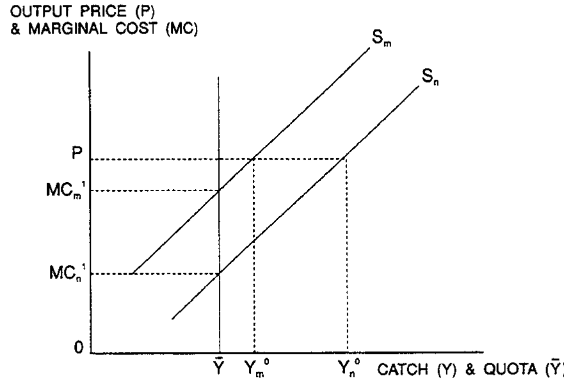

FIG. 1. Quota market for two vessels.

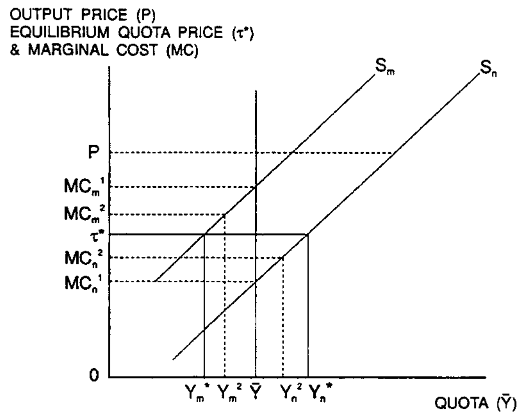

FIG. 2. Quota exchange process.

Figure 1 (Squires 1990) illustrates the quota market for two vessels m and n. The supply curve (equal to marginal cost and reflecting diminishing returns in this example) for vessel m lies above that for vessel n, indicating that vessel n is more efficient, i.e. can produce any given output level at lower cost. Prior to quota, both vessels face the same exogenous price for fish P, and vessel n (m) produces Y_n^0 (Y_m^0). Under a quota of $\bar{Y}$, vessel n (m) faces marginal cost MC_n (MN_m). Hence, $\tau_n = P - \text{MC}_n > \tau_m = P - \text{MC}_m$ and vessel n will buy quota from vessel m.

Figure 2 illustrates how quota exchange progressively narrows τ between vessels, until unit quota rents are equalized at the last unit traded, i.e. $\tau_m = \tau_n$, and the equilibrium ITQ price τ^* is formed. Initially, each vessel faces market price P and catches Y_m^0 and Y_n^0 (not shown). Each vessel is subsequently allocated $\bar{Y}$ and faces a unit quota rent of $\tau_m = P - MC_m^1$ or $\tau_n = P - MC_n^1$. Vessel m sells quota to vessel n, since $\tau_m < \tau_n$, causing τ_m to rise and τ_n to fall, reaching an intermediate position such as $P - MC_m^2$ and $P - MC_n^2$ with quota holdings Y_m^2 and Y_n^2. Trade continues until the unit quota rents are equalized for the last unit of quota exchanged, giving final quota holdings of Y_m^* and Y_n^*. In this two-vessel example, vessel n's final purchase ($\bar{Y} - Y_n^*$) equals that sold by vessel m ($\bar{Y} - Y_m^*$).

The efficient outcome after competitive exchange of quota is given by equalizing the net returns from holding quota, τ, across all N vessels in the industry, i.e. $\tau_1 = \tau_2 = \ldots = \tau_N = \tau^*$. In practice, τ^* differs between vessels by an amount equal to costs from transactions, information, transportation, risk, and uncertainty (these amounts vary by vessel).

Quota exchange amongst vessels gives gains from trade due to reduction in production costs (also called arbitrage efficiency). Economic rents from the species are maximized and gains from trade are enjoyed as less efficient vessels trade quota to more efficient vessels. The full economic rent generated by the resource, $\tau^*\bar{Y}$, where $\bar{Y}$ is the overall industry quota for the species, is also the revenue government receives if quota were initially auctioned at a single price or were placed under a uniform tax (Weitzman 1974; Anderson 1988). In theory, at least, the initial distribution of quota only affects the distribution of rents among vessels, not the efficiency after exchange (Montgomery 1972). If $\bar{Y}$ is optimal, then the equilibrium quota price formed after exchange, τ^*, is the marginal user cost of the unit resource (Moloney and Pearse 1979).

When linear programming is used to model the firm's short-run production technology (i.e. capital is fixed), short-run marginal costs (SMC) equal average variable costs (AVC) because of the constant returns to scale (a 1% increase in inputs yields a 1% increase in output) assumed in a linear programming model. Assuming competitive and exogenous prices, $\tau = P - \text{SMC} = P - \text{AVC}$. The unit quota rent prior to exchange τ, i.e. the firm's implicit marginal valuation of quota, is given with linear programming models by the shadow value of the quota constraint (the increase in profit with a one unit increase in the quota constraint). That is, the linear program measures the value of a unit quota to a vessel by estimating the change in a vessel's profits for an additional unit of quota. If Z denotes the vessel's short-run profits and $\bar{y}$ is the vessel's allocated quota, then $\tau = \delta Z/\delta \bar{y}$, where δ is partial derivative. The gains in net revenue with a one unit increase in $\bar{y}$ include net revenue gains from bycatch as well as from the regulated species because vessels can catch more of other species.

2.3. Sablefish Longliners of Columbia INPFC Area

The ITQ simulation was applied to the Columbia management region, which runs from Cape Blanco, Oregon (43°00′N), to Cape Elizabeth, Washington (47°30′N). The region's ports include Coos Bay, Waldport, Newport, Tillamook, Astoria, and Portland in Oregon and Illwaco and Westport in Washington. The relatively small number of ports makes the Columbia region an easy area in which to monitor landings, which would be important in an ITQ program.

Fixed gear (longline and fish pot) and groundfish trawl operators in the Pacific sablefish fleet dispute the allocation of allowable sablefish harvest, with fixed gear and trawl vessel groups each desiring a larger share. Strong Japanese sablefish demand for U.S. exports supports high ex-vessel prices of sablefish, further elevating the gear conflict in the sablefish fleet. These factors, the limited number of ports, longevity, and relative stability of recruitment to the sablefish biomass (which results in stable resource supply), make it a potential species for a market-based solution to the allocation issue.

2.4. Empirical Model

The linear programming model for the Columbia sablefish fishery is a modified version of that employed by Huppert and Squires (1987) to estimate the optimal size of the Pacific coast trawl fleet. The model maximizes the vessel's short-run profit (quasi-rent or producer surplus; Just et al. 1982), conditional upon the vessel or capital stock, subject to constraints on total allowable annual harvest and on vessel-weeks fished and the standard nonnegativity constraints (no variable is negative). The decision variable for each vessel is the number of weeks fished W_j in each quarter j (j = 1, 2, 3, 4) of the year, i.e. vessels vary weeks fished to maximize quasi-rent (short-run profits). The model is specified for each vessel as

$$(1)\quad \max_{W_j} Z = \sum_i \sum_j W_j (P_{ij} a_{ij} - \text{VC}_s)$$

subject to

$$(2)\quad \sum_j W_j a_{ij} \leq y_i \qquad \text{for all } i,$$

$$(3)\quad W_j \leq 10 \qquad \text{for all } j,$$

$$(4)\quad \sum_j W_j \leq \bar{W},$$

and

$$(5)\quad W_j \geq 0 \qquad \text{for all } j.$$

Quasi-rent for each vessel, Z, is total revenue less variable costs. The exogenous ex-vessel price for species $i = 1,\ldots,18$ in quarter j is denoted P_{ij}. Variable cost per week for vessel size class s ($s = 1,\ldots,5$), VC_s, is the short-run (operating) costs per week per vessel. The technical coefficients, a_{ij}, are weekly catch rates, i.e. tons of species i harvested per week by the vessel in quarter j. Each vessel's production limit for species i is denoted y_i. If the vessel is subject to quota, then for species i, $\bar{y}_i$ indicates the quota level for the individual vessel.

The first constraint, equation (2), represents the annual limits on each vessel's catch of species i. The second constraint, equation (3), constrains the harvesting activity of a longliner to 10 wk in a quarter. The third constraint, equation (4), is an annual constraint which requires the optimum annual sum of weeks fished by each vessel to not exceed the actual annual weeks fished $\bar{W}$. The actual weeks fished was less than the annual constraint of 40 wk implied by equation (3). The fourth constraint, equation (5), represents the standard nonnegativity constraint for the decision variable, weeks fished (W_j).

The 18 species potentially harvested by vessels are Dover sole (*Microstomus pacificus*), English sole (*Pleuronectes vetulus*), petrale sole (*Eopsetta jordani*), Pacific halibut (*Hippoglossus stenolepis*), other flatfish, lingcod (*Ophiodon elongatus*), Pacific cod (*Gadus macrocephalus*), Pacific hake (*Merluccius productus*), Pacific ocean perch (*Sebastes alutus*), widow rockfish (*Sebastes entomelas*), yellowtail rockfish (*Sebastes flavidus*), shortspine thornyhead (*Sebastolobus alascanus*), longspine thornyhead (*Sebastolobus altivelis*), other rockfish, salmon, albacore, shrimp, crab, and a group of other miscellaneous species. Over the course of the year, most vessels tend to concentrate production upon sablefish and some combination of halibut, lingcod, and rockfish.

The liner programming approach to optimizing the vessel's short-run profit is conditional upon existing vessel size, vintage (age), and state of technology (electronics, design, etc.). The underlying bioeconomic model is one of certainty and short-run static equilibrium. Hence, fish prices and input prices are assumed fixed and exogenously determined, fish stock densities and harvest rates do not depend upon the level of harvest, and the harvesting technology is constant (Huppert and Squires 1987).

These assumptions are reasonable for a vessel-level model of a region, since prices are determined coastwide over all gear types. Moreover, sablefish and thornyhead prices are likely to be exogenously determined in the Tokyo wholesale market (current research is addressing this issue). Dockside fuel prices are set by a standard mark-up procedure following the terminal price in Seattle or San Francisco. Some variation is observed coastwide, reflecting differences in marketing margins and perhaps product form and quality and competitiveness of the market structure.

Finally, the model does not consider the costs of management or optimal level of resource use. Instead, the optimal level of each ITQ-managed species, in this case only sablefish, is exogenously determined. Solving the long-run optimal level would require solution of each firm's long-run optimum level of capital stock, the optimum aggregate capital in the industry, and optimal abundance level.

2.5. Data and Variable Construction

A total of 139 longliners operated in the Pacific coast groundfish fishery in 1987 (PacFIN Research Data Base), of which 105 landed at least 0.5 metric ton of sablefish in the Columbia area (PacFIN Research Data Base). From these 105 vessels, the top 30 revenue producers or "highliners" were selected to insure individual vessels in the model covered their short-run costs and to simplify the modeling process.

Five size classes of vessels were selected for the study: (1) ≤15.0 m, (2) 15.1–16.0 m, (3) 16.1–18.0 m, (4) 18.1–20.0 m, and (5) ≥20.1 m. The size composition of the sample fleet, based on U.S. Coast Guard registered length, generally reflected the Pacific longline fleet. The number of vessels in each class was (1) 14, (2) 5, (3) 5, (4) 4, and (5) 2.

Highliners in Columbia landed approximately 20% of the sablefish landed coastwide by longliners during 1987 (Natural Resources Consultants 1988). The Columbia landings include multispecies catch (2519.52 metric tons) valued at $4.1 million (1987 U.S. dollars), consisting mainly of sablefish (889.87 metric tons) valued at $1.3 million. The mean ex-vessel price per metric ton for sablefish was $1606.30, which was higher than the coastwide 1987 ex-vessel price of $1040.00.

Technical coefficients a_{ij} were computed as weekly average catches (in metric tons) by quarter for each vessel from the 1987 PacFIN Research Data Base. Each "week" of fishing represents one calendar week in which at least one commercial landing was recorded. Week was selected rather than trip, since larger vessels make longer but fewer trips than smaller vessels and the latter may make several trips in a week. The choice of trip tends to otherwise overstate the time fished of smaller vessels.

Quarterly species prices were quarterly ex-vessel arithmetic means from the PacFIN Research Data Base. Variable costs included the costs of fuel, oil, provisions, ice, bait, gear replacement, crew, and bonuses. The labor costs were observed costs rather than estimates of opportunity costs. These cost data were obtained from a random sample survey of coastwide sablefish longline and fish pot vessels for 1987. Median rather than mean variable costs were computed because of the skewed and relatively limited sample size for each vessel size class.

2.6. Quota Allocation

Six different levels of overall quota $\bar{Y}$ were allocated among the 30 vessels for the simulation. The first overall quota was set at the total metric tons harvested by the sample of Columbia sablefish longliners in 1987. Subsequent industry sablefish quotas in the model were set at 90, 80, 70, 60, and 50% of the initial industry quota. Each vessel was allocated quota in proportion to its share of the actual catch in 1987 as a percentage of the target level, rather than in absolute units. In the model, quota is assumed issued without charge, to be freely transferable, and sufficiently divisible so that the small denominations and large numbers contribute to an active and competitive market in quota. The problem considers a certain and static environment and does not allow banking of quota for future use.

2.7. Derived Demand for Sablefish Quota

Demand curves show quantity demanded of a commodity as a function of its price and other exogenous factors. Inverse demand curves show price as a function of quantity demanded and the other exogenous factors.

Vessels have a derived demand for quota. That is, given ex-vessel fish prices and technology, the vessel's demand curve for quota is derived from final demand for that species and the vessel's costs and production technology (Squires 1990, 1991). To estimate the derived demand for quota used in the simulation model of the ITQ market, the linear programming model is first run to obtain estimates of the unit quota rent τ (which are the shadow prices for different vessel quotas $\bar{y}$). The vessel's inverse derived demand for the sablefish quota is then estimated by regressing τ upon the vessel's quota ($\bar{y}$) and dummy variables (D_s) for different vessel size classes, where the intercept α_0 represents the smallest vessels:

$$(6)\quad \tau = \alpha_0 + \sum_{s=2}^{5} \alpha_s D_s + \beta \bar{y}.$$

Ordinary least squares estimates are potentially biased because τ is censored at zero. That is, not all vessels are bound by quota, so that the shadow value derived from the linear programming model can be zero. In such instances, Tobin's censored regression technique is appropriate (Maddala 1985).

2.8. Equilibrium Market Quota Price

The estimated inverse derived demands for individual vessels, from equation (6), were summed over the N (30) vessels to get the inverse market-derived demand curve for an overall quota $\bar{Y}$:

$$(7)\quad \tau^* = \alpha_0 + \frac{1}{N} \sum_{j=2}^{N} \sum_{s=2}^{5} \alpha_s D_s + \frac{1}{N} \beta \bar{Y}.$$

The equilibrium market price for quota in the short run, τ^*, conditional upon the existing fleet capital stock, is the price that clears the ITQ market (the price for which demand equals supply) for the given, fixed supply of industry quota, $\bar{Y}$. This price is equivalent to that of an auction market or an optimal tax (Anderson 1988) and implicitly assumes that all units of quota are exchanged on the market. Thus, τ^* was determined

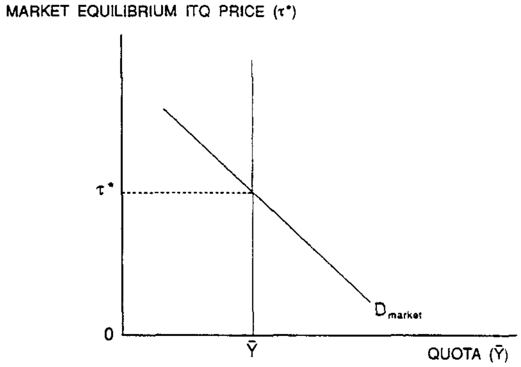

FIG. 3. Equilibrium market price for individual transferable quotas.

by evaluating equation (7) at $\bar{Y}$ ($=\Sigma\bar{Y}_i$). This aggregate quota $\bar{Y}$ forms the vertical (perfectly inelastic) sablefish industry quota supply curve. Figure 3 illustrates the market for one quota allocation. Six different values for τ^* were obtained, one for each $\bar{Y}$.

Shadow values from the linear programming model represent the value to the firm of an additional unit of output, including the value of the additional landed bycatch made available by relaxing the binding quota constraint. Hence, the market equilibrium price for sablefish quota can be greater than the ex-vessel sablefish price because τ incorporates the vessel's revenues from bycatch. Sample vessels were selected based upon minimum annual landings of 0.5 metric ton of sablefish rather than on a per trip basis. Some trips may have targeted more upon sablefish than other species. Hence, the contribution of bycatch to the unit rent of the sablefish quota, τ, may be overstated by the model.

2.9. Gains from Trade

Industry gains from trade are the difference between the industry rent after trade and the total industry rent before trade (but after the quota allocation), assuming all sablefish rents are valued in τ^*. Industry rent gains occur when vessels trade quota allocations $\bar{y}$, each vessel adjusting production and quota holdings to maximize quasi-rents (also called producer surplus or short-run profits; see Just et al. 1982). The total industry rent after trade is the area under the market demand curve for quota up to $\bar{Y}$. Given the linear demand curve, this area is $\tau^*\bar{Y} + 0.5[\alpha_0 + 1/N\Sigma\alpha_sD_s - \tau^*]\bar{Y} = 0.5[\tau^* + \alpha_0 + 1/N\Sigma\alpha_sD_s]\bar{Y}$. The total industry gains from trade at the competitive equilibrium market price, τ^*, are $0.5[\tau^* + \alpha_0 + 1/N\Sigma\alpha_sD_s]\bar{Y} - 0.5\Sigma[\tau + \alpha_0 + 1/N\Sigma\alpha_sD_s]\bar{y}$ (summing over all vessels for each of the six aggregate quotas $\bar{Y}$).

3. Empirical Results and Discussion

The linear programming model was run for the six different quota allocations for each of the 30 vessels. The subsequent data generated for the simulation were six sets of τ–$\bar{y}$ pairs for the 30 vessels. Equation (6), the firm's inverse demand for quota, was then estimated by Tobit analysis as discussed in Section 2.7.

3.1. Inverse Demand for Quota

The statistical significance of the vessel size class dummies in equation (6) was assessed by a log-likelihood test. The likelihood ratio test statistic for all dummy variables was 123.4 for four independent restrictions, indicating that the null hypothesis of no differences in unit rents among size classes could be rejected at the 0.01 level of significance. The three midsized vessel size classes have negative coefficients for the dummy variables; these coefficients were not individually statistically significant from zero but were as a group, since the chi-square statistic was 113.0 for three restrictions. Hence, the full model including all vessel size classes was retained (Table 1).

TABLE 1. Parameter estimates of vessel inverse demand curve for quota. An asterisk indicates statistically significant at 2%. Intercept is smallest vessel size class. Tobit analysis, giving maximum likelihood estimates. Log-likelihood −1485.5.

Variable	Coefficient	t-ratio	Significance
Constant	3308.16*	2.579	0.9911
Size two dummy	−2731.54	−1.261	0.8038
Size three dummy	−991.264	−0.486	0.4838
Size four dummy	−788.081	−0.352	0.3866
Size five dummy	38628.4*	13.150	1.00
Quota	−66.214*	−2.229	0.9853

TABLE 2. Equilibrium quota market price flexibilities.

Quota allocation	Price flexibility
Initial allocation	−0.24279
90% of initial	−0.20902
80% of initial	−0.19248
70% of initial	−0.18644
60% of initial	−0.18633
50% of initial	−0.18565

The positive sign of the statistically significant coefficients for the largest and smallest size classes indicated that these vessels have the largest unit quota rents τ (prior to exchange). The negative signs for the midsized vessels indicate inefficiency compared with the smallest and largest. Hence, the largest vessels, and possibly the smallest, should have the largest unit quota rents τ and purchase quota from the midsized vessels selling quota.

3.2. Elasticity of Market Demand for Quota

The price flexibility of τ^*, $\delta\ln\tau^*/\delta\ln\bar{Y}$, indicates the percentage change in equilibrium quota prices τ^* for a 1% change in the overall quota, $\bar{Y}$, i.e. the sensitivity of τ^* to changes in quota $\bar{Y}$. The estimated price flexibilities are inelastic, which means that a 1% increase in quota reduces τ^* by less than 1%, in this case 0.24%. Extreme short-run price variability is not expected. The price flexibility declines with tighter quotas (Table 2). An inelastic price flexibility is consistent with an elastic demand (Tomek and Robinson 1981), so that an increase in the ITQ market price by greater than 1% causes a greater than 1% decline in ITQ quantity demanded. Hence, market demand for quota is elastic.

An elastic market demand for quota suggests that total resource rents inversely vary with the level of quota, but that these proportional changes in resource rents are less than the proportional change in the aggregate quota. Hence, the fishery's economic rent can be maintained at nearly the same level over a broad range of overall quotas. This result should facilitate resource conservation, since conservative quotas could be used without a large opportunity cost of rent foregone. This suggests a conservative strategy that simultaneously protects the resource stock and insulates the industry against abrupt and large reductions in the overall quota if new stock assessments show a sudden population decline or that previous resource assessments were in error (Squires 1991).

3.3. Equilibrium ITQ Market Price

The market equilibrium prices for the sablefish ITQ, τ^*, conditional upon the existing fleet structure and vessel sizes, are reported in Table 3 for the six alternative levels of industry quota, $\bar{Y}$. For the initial allocation, τ^* was $3193. As expected, τ^* monotonically increased as $\bar{Y}$ decreased, peaking at $4175.83.

The values of τ^* are relatively high and are also relatively insensitive to the size of the overall quota level (reducing overall quota by 50% resulted in only a 31% increase in equilibrium ITQ price τ^*). The ITQ should generate an important asset value to initial holders of the right, unless the rights are initially auctioned or are taxed (which transfers some or all of the economic rent from the private sector to the public sector). Moreover, the ITQ has the potential to form a barrier to entry into a fishery with otherwise relatively limited capital requirements. It might be advisable to allocate some of the initial quota to crewmembers to allow the traditional upward mobility historically enjoyed.

The value for τ^* includes the gains in quasi-rents from species other than sablefish when the binding sablefish quota is relaxed. That is, when vessels are allowed to catch more sablefish in the model, they also catch more of other species, which also contributes to their revenues. The more efficient vessels are capable of using revenues from these other species to cross-subsidize purchase of quota. This also lowers unit costs of harvesting all species by spreading out annual fixed costs over greater volume of catch. This then increases overall competitiveness, particularly since much competition is based on output price. Hence, the largest vessels and those with a more diversified harvesting strategy (e.g. they may make targeted rockfish trips) are most likely to trade for quota.

3.4. Economic Rents

The total sablefish rent for the initial allocation of quota, given the capital stock and fleet structure and prior to trade, was $2.031 million (Table 3). This is the total rent implicit to a nontransferable quota. After exchange, total rent climbed to $3.138 million, a 67.35% gain from the initial overall quota due to trade and increased efficiency.

The potential size of the rent also suggests ample scope for the public sector to transfer some of the rent from the private sector to the public sector. One possibility is a tax or license fee (Grafton 1992). Auction markets for the initial allocation are also possible.

The proportional gains from trade depend upon the number of vessels exchanging quota. Initially, the most and least efficient vessels trade quota, since between them they enjoy the largest disparities in unit quota rents. Hence, they realize the greatest gains from trade and are least likely to be hampered by the relatively high costs of transactions and information that occur when ITQ markets are rudimentary and thin (few buyers and sellers). When the quota progressively tightened, the proportional gains from trade dropped considerably as the disparity between the efficient and inefficient vessels narrowed.

The results nonetheless indicated substantial gains in efficiency enjoyed through exchange of quota for all quota allocations (Table 3) and the importance of a fully specified property right structure. The relatively large potential rents indicated the size of rent dissipation due to open-access and the potential rents gained through rights-based management. The expected rents may be larger than the regulatory costs of planning, implementing, monitoring, and enforcing an ITQ program for sablefish. A complete cost-benefit analysis of an ITQ program can utilize the projected rents as part of economic benefits.

The reported rents and gains from trade are the maximum possible. In practice, less trade may be observed due to thin markets, private and sequential exchange between vessels rather than all quota exchanged in the ITQ market (all quota are exchanged in the simulation), transactions and information costs, and uncertainty (Noll 1982; Hahn and Noll 1983; Lindner et al. 1989; Lindner 1990; Atkinson and Tietenberg 1991). Markets also take time to form and efficiently operate.

These relatively large gains could reflect large intervessel differences in efficiency, but they may also reflect the relatively extreme solutions often found with linear programming (Shephard and Garrod 1980). Thus, intervessel efficiency differences may be heightened more with linear models than with models allowing for increasing marginal costs. Also, the potential rents are relatively large because they are short-run and hence exclude costs of capital and other fixed costs (e.g. insurance, moorage).

The results can be compared with the simulation results for a thornyhead transferable quota in the multispecies deepwater trawl fishery in Eureka for 1984 (Squires 1991). The proportional gains from trade in that study were generally less than 10%. The results are a bit difficult to compare because one study depends upon linear programming and maximization of quasi-rents and the other upon econometrics and maximization of revenues.

These results nonetheless suggest that a directed fishery may enjoy greater efficiency gains because of its greater flexibility in the product decision. That is, species mix decisions in a trawl fishery with joint production (multiple outputs produced by a single production process) reflect returns from several species, which must be weighed against one another. Moreover, there may well be lesser scope to alter production, to trade, and to

TABLE 3. Short-run equilibrium quota market price and total quota rent. Gains from trade are industry totals. Equilibrium market price in 1987 U.S. dollars per metric ton. Values estimated conditional upon existing capital stock.

Quota allocation	Market price for quota ($)	Fleet quota (t)	Total economic rent prior to trade ($)	Total optimum economic rent ($)	Gains from trade ($)	% gain in rent
Initial allocation	3193.79	889.87	2031074	3398956	1367822	67.35
90% of initial	3390.20	800.883	1295791	3137704	1841913	142.15
80% of initial	3586.59	711.906	2183023	2859015	675992	30.97
70% of initial	3783.02	622.909	1998154	2562782	564628	28.26
60% of initial	3979.42	533.922	1733107	2249101	515994	29.77
50% of initial	4175.83	444.935	1494112	1917946	423834	28.37

TABLE 4. Number of quota purchases for alternative quota allocations as a percentage of initial quota holding.

Vessel size class	100%	90%	80%	70%	60%	50%
1 (n = 14)	0	1	1	1	1	1
2 (n = 5)	0	0	0	0	0	2
3 (n = 5)	1	1	1	1	1	1
4 (n = 4)	0	0	1	1	1	1
5 (n = 2)	1	2	2	2	2	2
Total (n = 30)	2	4	5	5	5	7

TABLE 5. Number of quota sales for alternative quota allocations as a percentage of initial quota holding.

Vessel size class	100%	90%	80%	70%	60%	50%
1 (n = 14)	14	13	13	13	13	13
2 (n = 5)	5	5	5	5	5	3
3 (n = 5)	4	4	4	4	4	4
4 (n = 4)	4	4	3	3	3	3
5 (n = 2)	1	0	0	0	0	0
Total (n = 30)	28	26	25	25	25	23

enjoy gains from trade in a trawl fishery than in a directed longline fishery.

3.5. Concentration of Quota and Limitations to Quota Exchange

In practice, a well-formed price signal τ^*, such as that formed in the simulation, may not develop through extensive quota trade in competitive, well-functioning quota markets. In this case, the price signal does not fully and accurately convey the information for the most efficient resource allocation possible. A competitive market, with large numbers of buyers and sellers who actively trade permits, and a market clearing price do not necessarily develop (Noll 1982; Hahn and Noll 1982; Lindner et al. 1989; Lindner 1990; Atkinson and Tietenberg 1991). Even if the quota market is not concentrated (i.e. quota is not held by relatively few firms), the number of vessels deciding to trade their initial allocation of quota may be too few, the transactions may be strictly sequential, bilateral, and private (i.e. not appearing in the market), uncertainty may be important, or the unit size of quota may be too large, so that transactions are infrequent. In turn, infrequent trades and possibly highly variable price signals can undermine efficient choices of production, investment, and quota exchange and reduce the maximum expected economic rent and arbitrage efficiency. Along these lines, Lindner et al. (1989) and Lindner (1990) reported a widely dispersed price signal, relatively thin markets, and sequential and bilateral ITQ trade in New Zealand and provided a detailed discussion of the likely determinants of quota exchange and market performance.

Tables 4 and 5 report the pattern of quota purchases and sales in the simulation, in which all vessels have exchanged quota. Most vessels sell quota at all allocations, particularly the smallest vessels, and only a few buy, generally the largest vessels.

Vessels that sell quota sell all of it when trade is simulated with a linear model, since the unit quota rent τ is constant over all trade levels. Vessels compare this value τ with the ITQ market equilibrium price τ^* and if $\tau^* > \tau$, they sell all of their quota. In a model with upward sloping supply and marginal cost curves for sablefish, τ progressively declines (grows) as vessels buy (sell) quota. In this case, τ, equalized at the last unit exchanged among all vessels, can occur with vessels trading lesser amounts of quota than with the linear model. Hence, more balanced trade patterns can be expected. This issue is under research.

The simulated quota exchange indicates potential for concentration of quota by only a few vessels. The quota market risks becoming thin, noisy, and hampered by noncompetitive forces, potentially requiring limits to quota transfer and concentration — even when quota is initially allocated through auction markets.

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