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# Toward a More Complete Model of Individual Transferable Fishing Quotas: Implications of Incorporating the Processing Sector

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Economic analyses of individual transferable quota (ITQ) fisheries management traditionally have focused on the harvesting sector. However, harvester decisions impact the economic performance of co-dependent processing firms. This paper incorporates both sectors in an analysis of the effect of ITQs on commercial fisheries. Results show that, as a consequence of season elongation under a harvester-only allocation of fishing rights, capital nonmalleability implies that processor quasi-rents will be redistributed to harvesters. These losses could promote political gridlock and jeopardize adoption of an ITQ policy unless they are fully compensated or unless redistribution is avoided by a policy-superior initial allocation of rights to both harvesters and processors. 

## INTRODUCTION

Conventional economic wisdom holds rights-based individual transferable quota (ITQ) fisheries management as *prima facie* efficient in contrast to open access fisheries management. Wasteful common pool losses can be eliminated by assigning property rights over the open access fish stock [2, 18, 19, 23]. This conviction stems from the seminal article by Gordon [17], though, as Scott [29] points out, the roots of rights-based fishing can be traced to the Middle Ages.

A substantial theoretical literature concerning ITQs developed over the past several decades. This literature employs standard theorems of welfare economics to show that endowing individual harvesters with fully transferable, permanent, and exclusive fishing rights is tantamount to assigning property rights over the fish stock. Such an assignment of property rights provides incentives for efficient resource usage, thereby eliminating the perennial overcapitalization problem in the harvesting sector. An important benefit from privatizing open access fisheries, especially in fisheries managed by a total allowable catch (TAC), arises out of gains from free trade in which more efficient users of the resource are able to purchase rights from less efficient users. Such trade fully compensates the sellers.

Despite seemingly compelling arguments, fisheries economists have had limited success promoting a change in the property institutions that govern commercial fisheries. The reasons are numerous, though one stands out among all the other

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plausible explanations. Distributional conflicts can and do block changes in property rights [4, 5, 16, 19, 27, 30]. This simple principle has not received sufficient attention by fisheries economists who promote property rights as the key to improving allocative efficiency through market exchanges.

''Property rights are political institutions . . . (that) simultaneously define a distribution of wealth and political power'' [19, p. 7]. The ITQ promise of potential Pareto improvements is cold comfort to those vested under status quo open access property rights who expect loss of wealth or political power or both. It is in their rational self-interest to defeat policy change. And those participants who expect to gain can be relied upon to act as utility-maximizing rent seekers. For these reasons, anyone familiar with this fisheries policy issue can appreciate Shabman's [30] characterization of the process to change property rights as ''a dogfight among contending interests'' (p. 1031). The ability to promote ITQ fisheries management, for all of its carefully argued efficiency attributes, hinges upon designing property institutions that encourage policy change. ''If economics is to advise [fishery] policy, it seems difficult to believe that the distributional issue can simply be swept aside'' [13, p. 251].

This paper presents a benchmark analysis identifying distributional consequences of traditional rights-based economic remedies for fisheries management problems that pose political impediments to policy change. We build upon the literature in two fundamental ways. First, we relax the tacit assumption that only harvesters intervene between the fish population and the consumers. This assumption is false for most fisheries; the processing sector typically is as crucial to the utilization of fishery resources as is the harvesting sector, and the processing sector may be no less politically powerful. Nevertheless, consideration of the processing sector is conspicuously absent from the rights-based fishing literature. For that matter, it has received little attention in the general fisheries economics literature.[1] In fact, there is a widely held belief, which we show to be generally false, '' . . . that *if* the processing sector is perfectly competitive in the purchasing of fish, then the existence of this sector can be ignored in bioeconomic modeling of the fishery'' [9, p. 105].

With minor exceptions, like aboriginal claims and community development quotas, fisheries economists only have recommended allocating quota shares to harvesters. There has been no discussion as to how this asymmetric property rights allocation affects exvessel pricing efficiency or income distribution between two politically and economically powerful interest groups that are inextricably linked.[2]

[1] Notable exceptions address various aspects of imperfect competition in the processing sector; none are concerned with ITQ policy. Crutchfield and Pontecorvo [12], for example, suggested that efficient use of a common property resource might result from a monopsonistic processing sector. Clark and Munro [11] addressed the potential role for taxes and subsidies to correct price distortions caused by a monopsonistic processing sector confronting a competitive harvesting sector. Schworm [28] generalized [11] in the common property resource context in order to formally analyze the speculation of [12]. Munro [24] extended the results of [11] under the assumption that harvesters would react to monopsony by forming a raw fish bilateral monopoly. Matulich *et al*. [22] reconsidered Munro's [24] assumption of bilateral monopoly in the context of formula price contracting under uncertainty rather than in a game theoretic framework.

[2] It is not our purpose to consider all potentially impacted parties, e.g., potentially stranded human capital of nonowner-skippers. It is sufficient to show why the omission of the processing sector promotes political gridlock and jeopardizes adoption of ITQ management prescriptions by fisheries economists.

Second, our analysis focuses on the transition period as the industry adjusts from a TAC-managed open access equilibrium to an ITQ-managed equilibrium. This feature is unlike most of the ITQ literature which concentrates on the two long-run equilibria, with little attention paid to the economic effects in the transition period. Building upon Clark *et al*. [10], Lindner *et al*. [20] is an exception that recognizes the importance of the transition period as the harvesting industry (absent processors) adjusts to its new equilibrium. It is during this transition period (which they note can be quite long) that all rents are generated and winners and losers are defined. Once the industry reaches a long-run ITQ equilibrium, all fishery rents are capitalized into the value of quota share that then acts as a tax on quota share holders [7]. Accordingly, it is the transition period that may be of greatest importance to the policy process, but which has received virtually no attention.

This paper builds upon [20] by providing formal microeconomic analysis of both catcher and processor behavior during the transition period. The central issue in our paper is that the switch to rights-based fishing should recognize fixed assets regardless of where they occur in the fishery. Failure to recognize asset fixity by allocating the initial quota shares only to the harvesting sector will result in an unintended and unnecessary transitional, and possibly long-run, wealth transfer from processors to harvesters. In the long run, processors generally will be forced to exit the industry without compensation, and remaining processors can be either better or worse off.

Marshall [21] warned of the potential for wealth transfer whenever ‘‘composite quasi-rents’’ exist in an industry. Referring to this notion of composite quasi-rent as ‘‘expropriable quasi-rent,’’ Alchian [1] wrote

> If it arises with resources that have been made specific to each other in the sense that the service value of each depends on the other’s presence, the joint value of the composite quasi-rent might become the object of attempted expropriation by one of the parties, especially by the one owning the resource with controllable flow of high alternative use value (p. 142).

Since the quota share itself is perfectly malleable, and since the value of quota shares captures a minimum of all quasi-rents accruing to the initial recipients, then the initial recipients’ capital becomes perfectly malleable.[3] It follows that a harvester-only initial allocation renders harvesting capital perfectly malleable while processing capital (particularly shore-based processing capital) is not; processing capital will be the object of expropriation.

### *Assumptions*

In our economic analysis, we use a variant of the simple but powerful model of an open access seasonal fishery introduced by Clark [6, 8] and utilized by Munro and Scott [25]. We assume initially that:

1. A TAC has been imposed by the regulatory authorities and biomass has been stabilized;

[3]This statement presumes that the initial quota share allocation permits a harvest quantity exactly equal to the prior period.

2. The interaction of net natural growth and harvesting results in the restoration of the biomass to its original level by the beginning of each fishing season, and catch is constant per unit of fishing effort;

3. The fishing season has a maximum possible length of $T_{\max}$ days with the actual length determined by the time required for the fleet to harvest the given TAC;

4. The fleet begins with $n$ profit-maximizing vessels, each of which are making zero profit at the prevailing exvessel price;

5. No "crowding" stock externalities arise in the fishery;

6. The processing sector begins with $m$ profit-maximizing firms that process the seasonal harvest, TAC, and that are making zero profit at the prevailing final fish product price.

Our analysis abstracts from additional interesting open access fisheries problems for which continuous time bioeconomic models [7, 3] are appropriate (e.g., stock and congestion externalities). Such issues do not affect the qualitative conclusions of this paper, but serve only to exaggerate the consequences of fleet consolidation, season elongation, and quasi-rent transfer. Our comparative static equilibrium analysis builds upon time-dependent, firm level models proposed by Dano [14] and French [15] and allows a focused analysis of the primary issues relating to pricing efficiency and distributional effects of an ITQ policy. We defer potential control theoretic refinements of our main conclusions to future work.

We consider two polar cases concerning the nature of processing capital: perfectly nonmalleable and perfectly malleable capital. These two cases serve to bound the extent and duration of economic impact that a harvester-only initial allocation of quota has on the processing sector. Also, we assume initially that finished product price is unchanged by the switch to rights-based fishing. This assumption is subsequently relaxed to show that the analytical results are invariant with respect to finished product price.[4]

## THE ROLE OF TIME UNDER OPEN ACCESS

The purpose of this section is to formally establish the effect of time (season length) on both the fishers' and the processors' profit-maximizing behavior under open access. The open access profit-maximizing fisher chooses the optimal harvest rate consistent with a binding season length constraint, which corresponds to

[4] A constant finished product price assumption corresponds to a fishery in which: (i) a processed finished product form is unchanged by ITQ management; (ii) the wholesale buyer knows the total seasonal industry supply, e.g., a TAC-managed fishery; and/or (iii) season elongation under ITQ management does not constrain transactions demand for the finished product. An example of such a fishery is the North Pacific pollock fishery, which is being considered for ITQ management. The North Pacific pollock fishery is the largest in the United States, accounting for 31% of U.S. commercially harvested biomass in 1993 [26]. It is also one of the world's largest fisheries. Pollock are highly processed mainly into frozen surimi with no possibility for a fresh market. A higher price assumption corresponds to a situation in which ITQ management: (i) elongates the season sufficiently to undersupply transactions demand at open access prices, and/or (ii) enables fish to be sold in a higher valued product form. Noteworthy examples of ITQ fisheries that experienced dramatic finished product price increases include the British Columbia halibut fishery, which diverted catch from frozen to fresh product, and Australia's southern bluefin tuna fishery, which diverted all of the catch from local canned tuna processing to the Japanese sashimi market. Traditional processors were bypassed altogether.

higher marginal and average variable costs of fishing than could be achieved in the absence of the time constraint under nontransferable individual quota (IQ) or ITQ management. Processors are capitalized to use rates of processing that allow processing at minimum average cost, which yields zero economic profit. Market price and quantity equilibrium conditions require equality between the aggregate fleet rate of harvest and the aggregate processing sector demand for raw fish.

## *The Harvesters*

Consider a competitive profit-maximizing fisher in an open access fishery fishing at a rate of $\dot{R}_{\mathrm{f}}$ pounds of fish for $t_{\mathrm{f}}$ days in a given season. Let the harvesting technology of the fisher be such that $\dot{VC}_{\mathrm{f}}(\dot{R}_{\mathrm{f}})$ represents the rate of variable cost accumulation when fishing at rate $\dot{R}_{\mathrm{f}}$. Assume that the $\dot{VC}_{\mathrm{f}}$ function is increasing in $\dot{R}_{\mathrm{f}}$, the average variable cost function, $A\dot{VC}_{\mathrm{f}} = \dot{VC}_{\mathrm{f}}(\dot{R}_{\mathrm{f}})/\dot{R}_{\mathrm{f}}$, is strictly convex in $\dot{R}_{\mathrm{f}}$, and the marginal cost function, $\dot{MC}_{\mathrm{f}} = \partial \dot{VC}_{\mathrm{f}}(\dot{R}_{\mathrm{f}})/\partial \dot{R}_{\mathrm{f}}$, is strictly increasing above minimum $A\dot{VC}_{\mathrm{f}}$ (see Fig. 1, top left panel).

Now consider the seasonal variable cost function corresponding to harvesting $Y_{\mathrm{f}}$ pounds of fish in $T$ days. By definition,

$$VC_{\mathrm{f}}(Y_{\mathrm{f}}, T) \equiv \underset{\dot{R}_{\mathrm{f}},\, t_{\mathrm{f}}}{\mathrm{Min}} \left[ \dot{VC}_{\mathrm{f}}\left(\dot{R}_{\mathrm{f}}\right) t_{\mathrm{f}}: \qquad Y_{\mathrm{f}} = \dot{R}_{\mathrm{f}} t_{\mathrm{f}}, \qquad t_{\mathrm{f}} \leq T \right]. \tag{1}$$

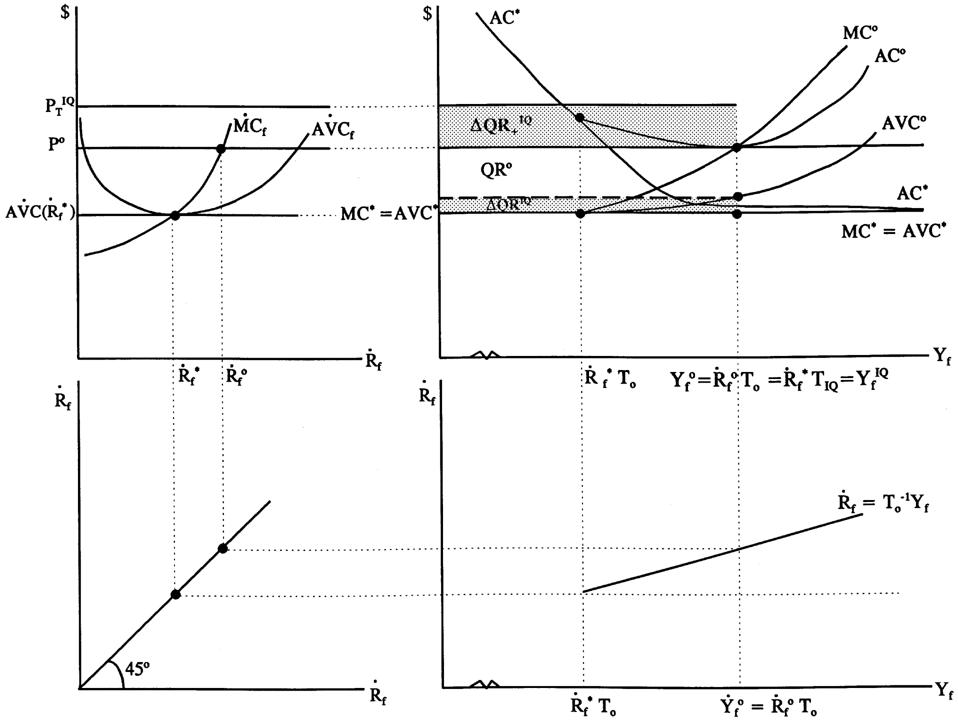


FIG. 1. Individual harvester behavior under open access and nontransferable quota management.

Letting $\dot{R}_{\mathrm{f}}^{*}$ denote the fishing rate that minimizes $A\dot{V}C_{\mathrm{f}}$, it is evident that

$$VC_{\mathrm{f}}(Y_{\mathrm{f}}, T) = \begin{bmatrix} \dot{V}C_{\mathrm{f}}\left(\dot{R}_{\mathrm{f}}^{*}\right)t_{\mathrm{f}} \\ \dot{V}C_{\mathrm{f}}\left(\dot{R}_{\mathrm{f}}\right)T \end{bmatrix} \quad \text{if} \quad \begin{bmatrix} t_{\mathrm{f}} = Y_{\mathrm{f}}/\dot{R}_{\mathrm{f}}^{*} \leq T \\ \dot{R}_{\mathrm{f}} = Y_{\mathrm{f}}/T > \dot{R}_{\mathrm{f}}^{*} \end{bmatrix} \tag{2}$$

(see [14, 15]). The definition of the variable cost function reflects the fact that the cost-minimizing fisher will operate at the most efficient harvest rate, $\dot{R}_{\mathrm{f}}^{*}$, provided that there is sufficient time to harvest $Y_{\mathrm{f}}$ pounds at this fishing rate. If not, then the rate of harvest must be increased to the rate $\dot{R}_{\mathrm{f}} = Y_{\mathrm{f}}/T$, such that $Y_{\mathrm{f}}$ pounds of fish are harvested in $T$ days.[5]

The preceding observations on fishers' cost functions leads to seasonal average variable cost and marginal cost functions with two distinct segments shown in Fig. 1, top right panel. So long as $Y_{\mathrm{f}} \leq \dot{R}_{\mathrm{f}}^{*} T_{\mathrm{o}}$, where $T_{\mathrm{o}}$ is the open access season length, seasonal marginal and average variable costs are constant and equal to the level $MC^{*} = AVC^{*}$. If $Y_{\mathrm{f}} > \dot{R}_{\mathrm{f}}^{*} T_{\mathrm{o}}$ then seasonal marginal and average variable costs increase as the rate of fishing increases, as indicated by the curve segments labeled $MC^{\mathrm{o}}$ and $AVC^{\mathrm{o}}$, respectively. The seasonal $AVC$ and $MC$ curves under open access are represented by joining the curve segments at $Y_{\mathrm{f}} = \dot{R}_{\mathrm{f}}^{*} T_{\mathrm{o}}$, yielding, $\overset{\frown}{AVC^{*}AVC^{\mathrm{o}}}$ and $\overset{\frown}{MC^{*}MC^{\mathrm{o}}}$.

Assuming that exvessel price equals $P^{\mathrm{o}}$, then the profit-maximizing fisher will equate price to marginal cost, resulting in an open access harvest rate equal to $\dot{R}_{\mathrm{f}}^{\mathrm{o}}$ and a seasonal harvest equal to $Y_{\mathrm{f}}^{\mathrm{o}}$. The relation $\dot{R}_{\mathrm{f}} = T_{\mathrm{o}}^{-1} Y_{\mathrm{f}}$ maps seasonal harvest into harvest rate in the bottom panels of Fig. 1. Quasi-rents accruing to the fisher are represented by the rectangular area labeled $QR^{\mathrm{o}}$ above the dashed line. In an open access equilibrium where all vessels earn normal returns, exvessel price will equal the minimum seasonal average cost of the fisher, and the fisher will be making zero profit, as illustrated in Fig. 1.

Regarding the aggregate behavior of the fleet under open access, fishers will deliver fish at the daily rate of $\dot{R}_{\mathrm{F}}^{\mathrm{o}} = \sum_{f=1}^{n} \dot{R}_{\mathrm{f}}^{\mathrm{o}}$, the fleet size being $n$. Seasonal harvest for the fleet is given by $Y_{\mathrm{F}}^{\mathrm{o}} = \dot{R}_{\mathrm{F}}^{\mathrm{o}} T_{\mathrm{o}} = \mathrm{TAC}$.

### *The Processors*

We make two fundamental assumptions in representing the technology of processing. First, the quantity of finished fish product from the daily quantity of raw fish processed is determined through a constant recovery rate. Second, the processor's cost function is separable: the nonfish variable cost of processing is separable from the raw fish cost. This separability, together with a constant recovery rate, results in the processor's variable cost function being linear in raw fish price.

Letting $\alpha$ represent the reciprocal of the product recovery rate, the rate of variable cost accumulation by the processor can be represented as

$$\dot{V}C_{\mathrm{p}}\left(\dot{R}_{\mathrm{p}}, P\right) = NF\dot{V}C_{\mathrm{p}}\left(\dot{R}_{\mathrm{p}}\right) + P\alpha\dot{R}_{\mathrm{p}}, \tag{3}$$

[5] An overcapitalized, open access fishery implies season length is always binding in $T_0$ days, i.e., a race to fish. A TAC-managed fishery further implies that fishers can reasonably anticipate $T_0$ based upon fleet size, routine announcements of catch-to-date, and advance notice of season closure.

where $N\dot{F}VC_p(\dot{R}_p)$ represents the minimum rate of nonfish variable cost accumulation when processing at a rate of $\dot{R}_p$ pounds of finished product and $P$ is the exvessel price paid for raw fish. The marginal and average variable cost functions corresponding to $\dot{V}C_p(\dot{R}_p)$ are given by

$$\dot{M}C_p\left(\dot{R}_p, P\right) = \frac{\partial N\dot{F}VC_p\left(\dot{R}_p\right)}{\partial \dot{R}_p} + \alpha P$$

$$A\dot{V}C_p\left(\dot{R}_p, P\right) = N\dot{F}VC_p\left(\dot{R}_p\right)/\dot{R}_p + \alpha P. \tag{4}$$

It is evident from (4) that any increase in the price of raw fish will cause a parallel upward shift in the marginal and average variable cost curves by an amount equal to the price increase times the reciprocal of the product recovery rate. Analogous to the fisher's case, we make the assumption that $\dot{V}C_p$ function is increasing in $\dot{R}_p$, the $A\dot{V}C_p$ function is strictly convex in $\dot{R}_p$, and the $\dot{M}C_p$ function is strictly increasing above minimum $A\dot{V}C_p$ (see Fig. 2, top left panel).

The profit-maximizing processor will equate final product price to marginal cost. Given the separability of raw fish costs, one can also characterize the profit-maximizing processor as equating final product price net of raw fish cost, $P_p - \alpha P^o$, with nonfish marginal cost, $NFMC(Q_p)$, where $Q_p = Y_p/\alpha$ and $Y_p$ is the quantity of raw fish that is processed. The top left panel in Fig. 2 shows that the processor will process at the open access rate of $\dot{R}_p^o$ and will produce a seasonal output of

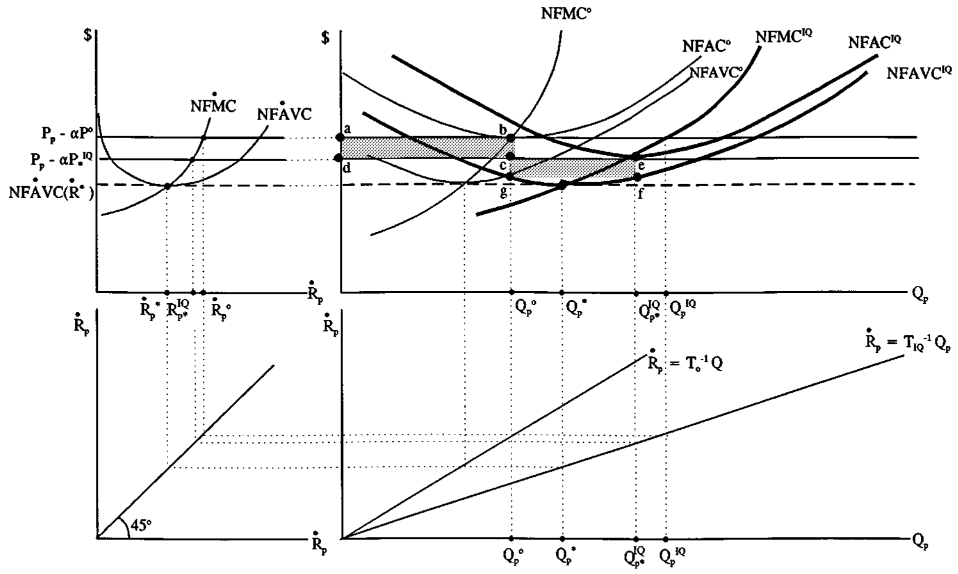


FIG. 2. Individual processor behavior under open access and nontransferable individual quota management.

$Q_{\mathrm{p}}^{\mathrm{o}}$, given an open access season length of $T_{\mathrm{o}}$ days, a final product price of $P_{\mathrm{p}}$, and an exvessel price of $P^{\mathrm{o}}$. The final product price net of raw fish cost will equal the minimum seasonal nonfish average cost of processing, and the processor will be making zero profit (an open access equilibrium characterized by normal returns).

Note that an individual processor's derived demand for raw fish is given indirectly by the portion of the $NFMC_{\mathrm{p}}^{\mathrm{o}}$ curve lying above the minimum $NFAVC_{\mathrm{p}}^{\mathrm{o}}$. Specifically, given a final product price, $P_{\mathrm{p}}, Y_{\mathrm{p}} = \alpha \arg_{Q_{\mathrm{p}}}[P_{\mathrm{p}} - \alpha P = NFMC_{\mathrm{p}}^{\mathrm{o}}(Q_{\mathrm{p}})] = f_{\mathrm{p}}(P)$ represents the quantity-dependent derived demand for raw fish by the $p$th processor under open access. A price-dependent derived demand for raw fish can be derived by equating $P_{\mathrm{p}} - \alpha P$ with $NFMC_{\mathrm{p}}^{\mathrm{o}}(Q_{\mathrm{p}})$, expressing $Q_{\mathrm{p}}$ in terms of liveweight equivalents, and solving for $P$ to obtain $P = \alpha^{-1}(P_{\mathrm{p}} - NFMC^{\mathrm{o}}(Y_{\mathrm{p}}/\alpha))$. It is evident that the slopes of the price-dependent derived demand and marginal cost curves are related as $\partial P/\partial Y_{\mathrm{p}} = -\alpha^{-2}\partial NFMC^{\mathrm{o}}/\partial Q_{\mathrm{p}}$. It is also evident that if output price were to increase, then the derived demand curve undergoes an upward parallel shift equal to the amount of price increase scaled by the product recovery rate.

Regarding the aggregate behavior of the processing sector under open access, processors will process raw fish at the rate of $\alpha \dot{R}_{\mathrm{P}}^{\mathrm{o}} = \alpha \sum_{p=1}^{m} \dot{R}_{p}^{\mathrm{o}}$, the number of processors being $m$. The seasonal amount of raw fish processed will be $Y_{\mathrm{P}}^{\mathrm{o}} = \alpha Q_{\mathrm{P}}^{\mathrm{o}} = \alpha \dot{R}_{\mathrm{P}}^{\mathrm{o}} T_{\mathrm{o}} = \mathrm{TAC}$.

## *Market Equilibrium*

The raw fish price, the seasonal quantity of raw fish harvested, the seasonal quantity of raw fish processed, and the number of operating harvesters and processors will be in equilibrium when the fleet rate of harvest is equal to the aggregate demand rate for raw fish by processors. The equilibrium raw fish price under open access is the value of $P$, say $P^{\mathrm{o}}$, that satisfies

$$\dot{R}_{\mathrm{F}}(P) = \sum_{f=1}^{n} \dot{R}_{\mathrm{f}}(P) = \alpha \sum_{p=1}^{m} \dot{R}_{\mathrm{p}}(P) = \alpha \dot{R}_{\mathrm{P}}(P). \tag{5}$$

Given a season length of $T_{\mathrm{o}}$, a total of $\mathrm{TAC} = T_{\mathrm{o}} \dot{R}_{\mathrm{F}}^{\mathrm{o}} = T_{\mathrm{o}} \alpha \dot{R}_{\mathrm{P}}^{\mathrm{o}}$ pounds of raw fish will be harvested and processed. The harvesting and processing price-quantity equilibrium for the industry operating under open access is illustrated in Fig. 3 by the intersection at point b of the sum of the harvesters' seasonal marginal cost curves above minimum $AVC_{\mathrm{f}}$, $Y_{\mathrm{F}}^{\mathrm{o}}(P)$, and the sum of the processors' seasonal derived demands for raw fish, $Y_{\mathrm{P}}^{\mathrm{o}}(P)$. If processors' capital is perfectly malleable, then $NFAVC \equiv NFAC$ in Fig. 2, so that aggregate derived demand for raw fish is zero when exvessel price exceeds $P^{\mathrm{o}}$ (assuming that $P_{\mathrm{p}}$ remains fixed). This implies that the derived demand for raw fish, $Y_{\mathrm{P}}^{\mathrm{o}}(P)$, is given by $P^{\mathrm{o}}$bc in Fig. 3. If processors' capital is nonmalleable, then $NFAVC < NFAC$, and processors will continue to operate (in the short run) even if exvessel price exceeds $P^{\mathrm{o}}$ (so long as variable costs are met), so that the curve albc represents $Y_{\mathrm{P}}^{\mathrm{o}}(P)$. The equilibrium price, $P^{\mathrm{o}}$, satisfies $Y_{\mathrm{F}}^{\mathrm{o}}(P) = T_{\mathrm{o}} \dot{R}_{\mathrm{F}}^{\mathrm{o}}(P) = T_{\mathrm{o}} \alpha \dot{R}_{\mathrm{P}}^{\mathrm{o}}(P) = Y_{\mathrm{P}}^{\mathrm{o}}(P)$.

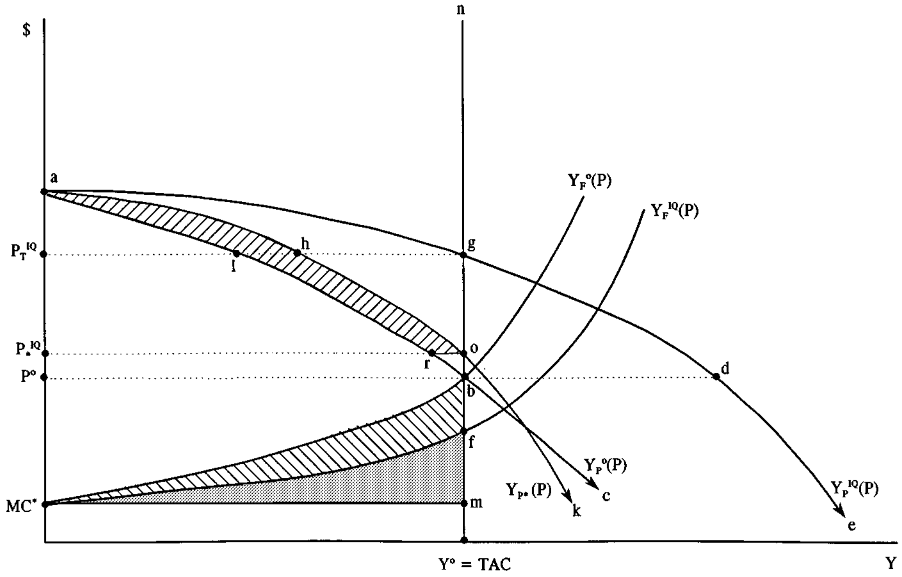


FIG. 3. Aggregate harvesting, processing, and price equilibrium

## SEASON ELONGATION AND QUASI-RENT TRANSFER UNDER HARVESTER-ONLY QUOTAS

Rights-based fishing in the form of individual harvester quotas relaxes the fishing time constraint and allows fishers to capture and retain additional ''fishing'' quasi-rents by operating in a protected supply-share environment. If processor capital is nonmalleable, the quota system allows fishers to capture processing sector quasi-rents because processors have no rights to the harvest. Season elongation creates excess processing capacity which leads to excess demand for raw fish at the original open access exvessel price. This, in turn, creates additional interprocessor price competition for raw fish. A new market equilibrium is achieved only after some processors are driven out of business without compensation and quasi-rents are transferred to (captured by) harvesters. Moreover, during the transition to a long-run rights-based equilibrium, all remaining processors are made absolutely worse off, earning below normal returns. This transitional loss can persist for an extended period of time depending upon the degree of processing sector capital nonmalleability. The more nonmalleable processing capital is, the greater and more persistent sector-wide losses will be. Only in the special case of perfect malleability are there no economic impacts on the processing sector.

### *Nontransferable Individual Quotas*

Consider the situation in which a nontransferable individual quota management system is implemented in the aforementioned TAC-managed open access fishery. Each fisher initially is assigned a percentage of the TAC in the form of nontransferable quota shares, $\omega_f$, that allow the fisher to catch the same percentage of the TAC as in the period preceding IQ implementation. Further assume that the TAC remains unchanged between the two policy periods such that the quota of fish the individual fisher may harvest is $Y_f^o = \omega_f \mathrm{TAC}$.

Once exclusive fishing rights are assigned, the individual fisher has no incentive to race to fish. He or she can harvest the same quantity of fish as under open access management, but at the slower, more efficient rate $\dot{R}_f^*$ that minimizes average variable cost and maximizes per unit and seasonal profit associated with harvest level $Y_f^o$. The slower daily fishing rate of harvesters elongates the effective fishing season to $T_{IQ} > T_o$. Thus, a prominent harvesting sector characteristic of rights-based fishing, even in the absence of transferability, is season elongation, increased harvesting efficiency, and higher profits relative to open access management.

The impact of an IQ management system on fishing costs and the behavior of fishers is depicted graphically in Fig. 1. Fishing at the efficient rate $\dot{R}_f^*$ for $T_{IQ} > T_o$ days, the fisher's average, average variable, and marginal cost curves are given by $AC^*\frown AC^*$, $AVC^*\frown AVC^*$, and $MC^*\frown MC^*$. It is assumed that any biologically determined season length is greater than or equal to $T_{IQ}$ days so that the quota can be harvested at rate $\dot{R}_f^*$.[6] In the absence of a change in the price of raw fish, season elongation induced by IQ management allows fishers to increase quasi-rents. Recall that the harvester's quasi-rents under open access equal the unshaded rectangular area labeled $QR^o$ in Fig. 1. This is the area above the dashed line and below the $P^o$ price line. The harvester will continue to harvest $Y_f^o = \omega_f \mathrm{TAC}$ at price $P^o$ under an IQ system. However, given the changes in the cost structure of the fisher under IQ management, the harvester's quasi-rents increase by the shaded area labeled $\Delta QR^{IQ}$ in Fig. 1. This area represents the intended efficiency gain by harvesters under the IQ policy. Every fisher now has an excess demand for quota shares since, from the standpoint of individual fishers, each additional pound of fish harvested returns a positive profit because $P^o > MC^*$. The nontransferability provision of IQ management locks fishers into this excess demand situation and fixes the fishers' increase in fishing quasi-rents at the level $\Delta QR^{IQ}$. The aggregate supply function of the harvesting sector rotates to the right, depicted by $Y_F^{IQ}(\mathrm{P})$ in Fig. 3, which reflects the lower harvesting costs. The aggregate fishing quasi-rent gains by harvesters is given by the crosshatched region $MC^*\mathrm{bf}MC^*$.

The increase in fishing quasi-rents that results under the open access exvessel price, $P^o$, does not include the unintentional (from a policy standpoint) potential increase in revenues due to higher raw fish prices associated with lower delivery rates under the quota system. Referring to Fig. 2, reduced harvest rate and concomitant season elongation to $T_{IQ} > T_o$ days increases effective seasonal processing capacity of a given processor, as indicated by the rightward-shifted cost curves having the IQ superscript, with *NFAC* shifting downward to reflect the declining nature of average fixed costs. Assuming no change in final product price, the quantity of raw fish demanded at the prevailing exvessel price increases to $Y_p^{IQ} = \alpha Q_p^{IQ} > \alpha Q_p^o = Y_p^o$. The sum of processors' quantities demanded exceeds harvest, creating an excess demand situation. Whether this excess demand translates into a higher exvessel price depends on whether processors' capital is perfectly malleable.

[6] If maximum season length were constraining, then a second set of upward-sloping cost curves would appear in Fig. 1 at the point where $Y_f$ could no longer be harvested at rate $\dot{R}_f^*$. Harvester quasi-rent gains identified subsequently would diminish but not vanish.

Assuming perfect malleability, $NFAVC \equiv NFAC$ so that processing firms cease to operate if exvessel price exceeds $P^{o}$. Excess demand then causes a sufficient number of processors to exit such that exvessel price remains unchanged and derived demand equals TAC. This situation is depicted in Fig. 3, where the aggregate derived demand function for raw fish, $Y_{\mathrm{P}}^{\mathrm{IQ}}(P)$, is given by the curve $P^{o}$bde, which represents the horizontal summation of the expanded derived demand functions of individual processors under IQ management. In this perfectly malleable case, harvesters do not obtain quasi-rent transfers from the processing sector, and exiting processors experience no quasi-rent losses.

If processor capital is nonmalleable, then $NFAVC < NFAC$; a given processing firm will continue to operate in the transition period so long as exvessel price is such that $P < \alpha^{-1}[P_{\mathrm{p}} - \min(NFAVC_{\mathrm{p}})]$. The aggregate derived demand for raw fish in this case rotates out to the curve agde (Fig. 3), representing the horizontal summation of individual processors' expanded derived demand functions. Exvessel price increases during the transition period to $P_{\mathrm{T}}^{\mathrm{IQ}}$, and a representative harvester gains additional quasi-rents indicated by the shaded rectangular area labeled $\Delta QR_{+}^{\mathrm{IQ}}$ in Fig. 1. The aggregate short-run increase in quasi-rents accruing to the harvesting sector due to the unintended exvessel price increase when processing capital is nonmalleable is indicated by the rectangular region $P_{\mathrm{T}}^{\mathrm{IQ}}$gb$P^{o}$ in Fig. 3. Thus, the presence of nonmalleable processing capital causes transitional quasi-rent gains in the harvesting sector to arise not only from the policy-designed increased harvesting efficiency (area $MC^{*}$bf$MC^{*}$)—which also occurs in the case of perfectly malleable capital—but also from the unintended appropriation of processing sector quasi-rents (represented by the difference in areas defined by $P^{o}$bla $-$ $P_{\mathrm{T}}^{\mathrm{IQ}}$ga).

Closer examination of processing sector impacts under nonmalleable capital is informative. Based on Fig. 2, processing firms sustain uncompensated losses in the transition period whenever processing capital is nonmalleable since $P_{\mathrm{p}} - \alpha P_{\mathrm{T}}^{\mathrm{IQ}} < P_{\mathrm{p}} - \alpha P^{o}$ implies that $P_{\mathrm{p}} - \alpha P_{\mathrm{T}}^{\mathrm{IQ}}$ lies below $NFAC^{\mathrm{IQ}}$ at the original output level $Q_{\mathrm{p}}^{o}$, and total industry output is fixed at $\sum_{p=1}^{\mathrm{m}} Q_{\mathrm{p}}^{o} = \mathrm{TAC}$. Processors for which $P_{\mathrm{p}} - \alpha P_{\mathrm{T}}^{\mathrm{IQ}}$ is less than the minimum $NFAVC^{\mathrm{IQ}}$ cease to operate. In order to reestablish a sustainable equilibrium in the long run, processing firms must leave the industry until remaining processors achieve a zero profit position, implying that long-run exvessel price eventually attains equilibrium at $P_{*}^{\mathrm{IQ}}$, where $P^{o} < P_{*}^{\mathrm{IQ}} < P_{\mathrm{T}}^{\mathrm{IQ}}$. A typical surviving firm would operate at seasonal level $Q_{\mathrm{p}*}^{\mathrm{IQ}}$ depicted in Fig. 2. As processing capacity exits the industry, the aggregate derived demand function of remaining processors, $Y_{\mathrm{P}*}^{\mathrm{IQ}}(P)$, rotates inward, as indicated by the curve ahok in Fig. 3.

Relative to the open access situation, it is an empirical question whether a surviving processor will experience increased or diminished seasonal quasi-rents. Quasi-rents will increase for the firm only if gains due to increased processing efficiency and market share (quadrangle cefg in Fig. 2) exceed quasi-rent losses due to permanent price concessions (rectangle abcd). Similarly, it is an empirical question whether the sector of surviving processors experiences increased or diminished aggregate quasi-rents. The sectorwide quasi-rent gain in processing efficiency is given by the crosshatched area ahorla in Fig. 3, while the loss attending exvessel price concessions equals the rectangle $P_{*}^{\mathrm{IQ}}$ob$P^{o}$. Whether there are long-run sectorwide gains or not does not diminish the fact that the subset of processors forced to exit the industry forfeit quasi-rents without compensation of any kind because processors have no property rights to the fish resource.

In the event that the switch to rights-based fishing causes the final product price, $P_{\mathrm{p}}$, to increase, every processor's derived demand undergoes a parallel upward shift by the amount of the price increase multiplied by the product recovery rate, as argued previously. The aggregate derived demand for raw fish also undergoes a parallel upward shift, resulting in a higher (by the amount of the parallel shift) exvessel price. Quasi-rents accruing to the processing sector are the same as before the output price change.[7] On the other hand, the harvesting sector captures all of the additional revenue and, thus, accrues all of the quasi-rents generated from the output price change.

In summary, implementation of a nontransferable, harvester-only quota management system in a TAC-managed fishery results in increased harvesting efficiency, reduced fleet harvest rates, season elongation, and increased quasi-rents accruing to the harvesting sector. Concomitantly, processor quasi-rents are transferred to the harvesting sector in the transition period if processing capital is nonmalleable. A subset of processors are eventually forced to exit the industry and forfeit quasi-rents without compensation. Additionally, the surviving processing sector will become more efficient in the long run if processing capital is nonmalleable but must sustain permanent price concessions. Whether surviving processors sustain gains or losses in individual/aggregate producer surplus is an empirical question.

### *Individual Transferable Quotas*

The transferability provision of ITQ management accentuates the preceding analytical results. Transferability allows the purchase and sale of quota shares which promotes fleet consolidation, additional harvesting efficiency, a further reduction in fleet harvest rate, further seasonal elongation, and additional quasi-rent gains by the harvesting sector. Additional season elongation forces more processors to exit the industry and, provided that processor capital is nonmalleable, additional quasi-rents are transferred from processors to harvesters in the transition period. Processors' quasi-rent is forfeited without compensation. Long-run individual and aggregate producer surplus of surviving processors could increase or decrease.

These results can be shown by beginning where IQ management ended. Assume the initial quota share allocation, $\omega_{\mathrm{f}}$, yields the same harvest level, $Y_{\mathrm{f}}^{\mathrm{IQ}} = Y_{\mathrm{f}}^{\mathrm{o}} = \omega_{\mathrm{f}}\mathrm{TAC}$, as under either TAC-managed open access or IQ management. The following decision rules determine the profit maximizing fisher's quota holding behavior under the assumption that a rental market exists for quota and that $s$ denotes the quota share unit rental price. If

$$P - MC_{\mathrm{f}}^{*}\left(Y_{\mathrm{f}}^{\mathrm{IQ}}\right)\left\{\begin{array}{c} > s \\ = s \\ < s \end{array}\right\}, \qquad \text{then} \left\{\begin{array}{l} \text{acquire quota} \\ \text{optimal quota} \\ \text{sell quota} \end{array}\right\}.$$

[7] This conclusion warrants an important caveat because it assumes the traditional fisher-processor reliance is unaltered. If ITQ policy facilitates a product form change that allows fishers to bypass processors (the case of British Columbia halibut or Austalian southern bluefin tuna), then all processing quasi-rents will be permanently expropriated.

Fishers will sell all of their quota and not fish if $P - MC_f^*(Y_f^{IQ}) < s$, while they will acquire as much quota as possible providing $P - MC_f^*(Y_f^{IQ}) > s$. Less efficient harvesters will exit the fishery with compensation derived from the sale of quota. The most efficient harvesters ultimately will own all quota shares and will harvest the TAC at the minimum possible cost. In the polar case, the most efficient core fleet would consist of identical vessels, each fishing at the same rate $R_f^*$ and at marginal cost $MC_f^*$ until the TAC is harvested. This polar case is exhibited in Fig. 3 by the supply function $MC^*$mn which is horizontal at the level $MC^*$ until the TAC is reached at point m, after which the supply function becomes vertical. In the absence of any exvessel price increase, the quasi-rent gain to the harvesting sector (relative to the nontransferable IQ situation) is represented by the shaded area bounded by $MC^*$fm$MC^*$. This gain is intended by ITQ policy.

The impact of ITQ management on processors is qualitatively the same as that under IQ management, but magnitudes of impacts are accentuated. The decreased number of fishers further reduces the fleet harvest rate, which elongates the season. The rate-quantity line in the lower right quadrant of Fig. 2 rotates toward the $Q_p$ axis causing processors' seasonal cost curves to shift further to the right so that excess processing capacity is accentuated. Average total cost further decreases as fixed costs are spread over greater output. If processing capital is nonmalleable, additional short-run upward pressure on exvessel price occurs causing additional unintended quasi-rent transfers from processors to harvesters. In the long run, additional less efficient processors must exit the industry and their quasi-rents are forfeited without compensation. The TAC ultimately will be processed more efficiently than under IQ management, but efficiency gains accruing to processors will be at least partially if not fully offset by further exvessel price concessions. The short- and long-run situations could be depicted in Fig. 3 by curves rotated to the right of both $Y_P^{IQ}(P)$ (curve agde) and $Y_{P^*}^{IQ}(P)$ (curve ahok). These are not drawn so as to avoid complicating the figure. If output price increases, a parallel upward shift occurs in the derived demand of processors, resulting in an increase in the exvessel price equal to the size of the upward shift. Any increased revenues, and thus, increased quasi-rents, accrue entirely to the harvesting sector, as in the case of IQ management.

If processing capital is perfectly malleable, aggregate processor derived demand is given by a rightward elongated version of the curve $P^o$bde in Fig. 3, so that exvessel price remains at $P^o$. The harvesting sector gains the intended fishing quasi-rents bounded by $MC^*$fm$MC^*$ but gains no quasi-rent transfers from individual processors. The processing sector neither forfeits nor gains quasi-rents.

## DISCUSSION

Inclusion of the processing sector is essential to analyzing both pricing efficiency and distributional impacts of a switch to rights-based fisheries management whenever processing capital is less than perfectly malleable. Open access property institutions that cause fleet overcapitalization and the race to fish also foster a level of capitalization in the processing sector sufficient to service the accompanying race to process. A traditional, harvester-only initial allocation of transferable fishing rights has the intended impact of ridding the harvesting sector of redundant capital. However, such an asymmetric ITQ policy design impacts the cost structure and exvessel pricing behavior of the processing sector both temporarily during the transition from an open access equilibrium to a long-run ITQ equilibrium, and also permanently once a long-run ITQ equilibrium is established.

The singular focus on problems related to an overcapitalized harvesting sector has caused the profession to recommend ameliorative policies that do not fully reflect the institutional structure of commercial fisheries nor the political realities of changing property institutions. The analysis presented in this paper demonstrates that in the usual presence of less than perfectly malleable capital, a traditional ITQ policy design unintentionally disenfranchises the codependent processing sector by transferring some of its composite quasi-rents to the harvesting sector during the transition period—possibly even in the long run. Some processors will be forced to exit, transferring their entire wealth to the harvesting sector through exvessel price concessions. Others that do survive will have forfeited some quasi-rents to the harvesting sector during the transition period—possibly a long period of time. This conclusion derived from the fact that during the transition period the price of quota shares captures not only resource rents but also the quasi-rents to all fixed factors dedicated to the fishery. Both the duration and the extent of transitional losses in the processing sector are increasing functions of the degree of capital nonmalleability.

We also showed that once processors exit and a long-run ITQ equilibrium is established, surviving processors may gain or lose quasi-rents (nominal dollars) relative to the status quo open access equilibrium. Even if total processing sector surpluses eventually were to increase in the long run (an empirical question), this possibility is hardly consensus building in the political forum where policy change is decided. All policy-induced losses to the processor are uncompensated. We believe that this is a major impediment to adopting market exchange solutions to fisheries management. Only if processing capital were perfectly malleable would the much discussed increase in harvesting quasi-rents derive only from efficiency gains in the harvesting sector. One would be hard pressed to identify such a fishery, unless the entire fishery were vertically integrated.

The mechanism of regulatory quasi-rent expropriation was identified in this paper and shown to be independent of a change in finished product price. A harvester-only initial allocation gives fishers the flexibility to reduce the daily rate of harvest and extend the season, thereby lowering the marginal and average variable costs of fishing until unit quasi-rents are maximized. Furthermore, fishers can consolidate (further elongating the season) through quota-share trading under the protection of explicit harvesting rights that guarantee all trades are fully compensated. The fleet will consolidate to a core of efficient vessels for which further gains from quota trade are not possible.

Processors receive no such protection; they must choose their optimal rate of throughput consistent with the season length determined by the harvesting sector. For a given TAC, season elongation reduces throughput per day in a processing sector that was initially capitalized to meet the throughput requirements of overcapitalized, open access fisheries. This creates additional processing capacity and associated excess demand per unit of time for raw fish at open access exvessel prices. Unlike the harvesting sector, however, processors lack the rights necessary to operate in a protected excess demand situation or to purchase processing rights from a less efficient competitor. Instead, processors eliminate their excess demand for raw fish by bidding up exvessel price, and thereby, transfer some or all of their status quo processing quasi-rents to the harvesting sector. Raw fish market price and quantity return to equilibrium only when the aggregate fleet rate of harvest equals the aggregate processing sector demand for raw fish. Remaining processors could benefit or lose in the long run depending upon the relative strength of processing efficiency gains versus losses attending permanent price concessions.

Annual compensation equal to their lost quasi-rents would leave processors no worse off and avert political gridlock. Such compensation, if it could be empirically defined (a doubtful proposition), presumably would be funded through a quota or landings tax. However, Section 1854(d) of the Magnuson Act [31] specifically forbids charging fees in excess of the administrative costs incurred in issuing limited access permits.[8] Alternatively, the regulatory quasi-rent expropriation question could be avoided altogether by pursuing a policy-superior initial allocation in which symmetrical rights are issued to both sectors.[9] By symmetrical, we mean an initial allocation of rights that preserves the distribution of wealth prior to quota-share trading and also preserves the status quo price formation process. The intent of a symmetrical rights distribution would be to ensure that subsequent transfers of rights by all parties were fully compensated through the market for these rights.

The optimal specification of such a symmetric rights assignment is not obvious and deserves further research. Candidates worthy of consideration include: (i) a split of harvest quota shares between fishers and processors; (ii) a ‘‘two-pie’’ allocation, in which catching rights are awarded to fishers and processing rights are awarded to processors; and (iii) full-utilization quota shares, in which fishers and processors are each awarded a paired bundle of catching and processing rights. A ‘‘use-it-or-lose-it’’ provision may be required so that the TAC is not reduced for vicarious (conservation) use at less than its full market value—the value of catching plus processing net of variable costs. In any case, the results of this paper suggest the need for considering alternatives to the traditional ITQ scheme of endowing fishers with property rights and endowing processors with the consequences.

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[8] At the time this paper was written, this restriction on fees was being debated in Congress. Reauthorization of the Magnuson Act [31] may permit charging fees to cover agency costs of limited access management. However, there is no consideration of a tax substantial enough to redistribute the unintentional, policy-derived rents back to the processing sector.

[9] Current interpretation of the Magnuson Act [31] prohibits regulating (assigning rights to) processors. However, this interpretation is also being debated in Congress and is subject to change with reauthorization. The regulatory expropriation resulting from a harvester-only allocation of quota constitutes a ‘‘denial of reasonable investment-backed expectations,’’ which is arguably a taking under the Fifth Amendment of the U.S. Constitution. The impetus for a change in interpretation is strong.

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