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Flexibility and Strategic Behaviour in the Market for ITQs

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Abstract:

In this article we show benefits of quota flexibility in a single-stock fishery model where one of the firms is allowed to behave strategically in the trading of quotas while other firms in the fishery are price takers. The ex-vessel price for fish is assumed constant. Quota flexibility is implemented through a settlement at the end of each regulation period. In that settlement firms having unused quotas are compensated by a subsidy, while those who have quota shortfalls are obligated to pay a tax. For the same deviation the tax is higher than the reward. Former literature shows that market power under a traditional ITQ system can lead to inefficiencies. However, losses due to market power can be subdued when quotas are more flexible. A simple argument to account for this view is that the competitive fringe of firms in the flexible case have the option to make use of the tax/reward system. Thus, rather than being exploited by the price manipulating firm the competitive fringe might find it better to deviate from the 1:1 "quota — realized catches"- relationship that characterizes competitive equilibrium.

1. Introduction

In recent decades, incentive adjusting approaches such as individual catch quotas have become the preferred way of managing fisheries. This is because such instruments may achieve outcomes that are socially efficient by inducing harvesters with incentives to minimize cost of harvesting their quota amount. Even if quotas are transferable, they are still fixed in the short run, and they might increase the incidence of discarding and misreporting of catches. This might be one of the reasons why some kind of flexibility is often introduced, such as allowing for harvests above quotas but where excess realized quantities are paid for instance with 20% of original price. Here we show a more systematic approach where the solution to the latter problem is to make quotas more flexible by replacing transferable quota shares with a system of tradable shares combined with a tax/reward scheme (Berglann, 2012). Moreover, Berglann (2023) shows that this system can function very good under uncertainty of costs and stock size assessments.

However, the issue of market power in such flexibility regimes has yet to be discussed. This paper contributes to the literature by solving explicit expressions for harvesting, quota price, and efficiency loss in this regime. All firms are price takers in the market for sales of fish. However, following Hahn (1984), Hatcher (2012) and Helgesen (2022), we begin that exploration with the ‘‘benchmark’’ case where at least one firm is a price taker in the quota market and where a dominant firm can exert market power.

2. Optimal stock size

First, we want to determine a number for the optimal stock size in the case of a fishery regulated to obtain the Maximum Economic Yield (MEY) output. We solve a Gordon-Schaefer bioeconomic model (Bjørndal & Munro, 2012) for steady state. Total harvest is $h = h(z, X) = z\,X$ given as a function of stock size X and total catch-effort $z = q\,e$ consisting of catchability coefficient q and total effort e. Steady state means that there is no change in stock size X, i.e.,

$$\frac{\partial X}{\partial t} = F(X) - z\,X = 0 \tag{1}$$

where $F(X)$ is the growth function. To find analytical expressions, we use the logistic natural growth equation,

$$F(X) = r\,X\,(1 - X/K) \tag{2}$$

where r is the intrinsic growth rate and K the carrying capacity of the environment. Assuming steady state (1), for $X > 0$, the stock-effort relationship becomes

$$X(z) = K - \frac{K}{r}\, z \tag{3}$$

Assuming constant price p for fish, optimal total profit π is

$$\pi = \max_z [p\, z\, X(z) - \; C(z)] \tag{4}$$

where z is total catch-effort and where

$$C(z) = (c/2)z^2 \tag{5}$$

is the (quadratic) function of cost of catch-effort for the fishery. This formulation describes the profit of a price-taking sole owner fishery where all fishing rights are held by one firm that controls all vessels. Concavity ensures an inner solution to (4). This optimal solution is called the maximum economic yield (MEY) level. The first order condition for solving (4), when (3) is inserted, becomes

$$p\, X(z) \; + \; p\, z\, X'(z) - c\, z \; = p\, K - \frac{2\, p\, K}{r} z - c\, z = 0\,. \tag{6}$$

which give optimal catch-effort for a single owner (SO)

$$z_{SO} = z = \frac{p\, K\, r}{2\, p\, K + c\, r} \tag{7}$$

and from (3) equilibrium MEY stock size. Here we apply the mean cost parameter c

$$x = x_{SO} = X(z_{SO}) = \frac{K(p\, K + c\, r)}{2\, p\, K + c\, r} \tag{8}$$

In the following we will treat equilibrium stock size as a constant $x = x_{SO}$ which enable us to write equilibrium individual catches as $h_i = z_i\, x$ and total catches as $h = z\, x$.

3. Competitive Flexible ITQs

We present the following scheme: Prior to the commencement of fishing, the estimated values of the stock function parameters K and r, along with the equilibrium stock size x (as derived from Equation 8) are disclosed and published to ensure they become common knowledge. These parameter values will be used in the regulation scheme during the forthcoming regulation period. To avoid adaptation behaviour the planner promises that these values will not be updated within the period. Thereafter, each firm i in the industry is informed that its revenue for landed fish will not be paid out through regular sale channels. Instead, they will be compensated by the regulation authorities by a reward R_i minus a tax t_i.

The above scheme can be rephrased in the following context: *"Benefits"* to firm i if there is no stock degradation from fishing is given by the first part of the stock-effort relationship (3), i.e., revenues minus the firm's costs

$$B_i(h_i) = R_i(\, h_i) - C_i(\, h_i) = p\, h_i\, K/x - c_i/(2\, x^2)\, h_i^2 \tag{9}$$

where $R_i(\, h_i)$ is the reward and c_i is parameter of the quadratic catch-effort cost function (5) $C_i(\, h_i)$.

"Damage" to the stock caused by fishing mortality owing to industry catches $h = z\, x$ is derived from the second part of (3)

$$D(h) = p\, K/r\, (h/x)^2 \tag{10}$$

where $h = \sum h_i$. Equation (10) is essentially the value of the reduction in stock size due to fishing effort. As said, in addition to the reward $R_i(\, h_i)$, the scheme prescribes that each firm *i* pays a tax for its share of this total damage (10). More specifically, firm *i* compensate for its fishing by paying a quadratic tax equal to

$$t_i = T(h_i, s_i) = s_i D(h_i/s_i) = s_i\, p\, K/(r\, x^2)\, (h_i/s_i)^2 \tag{11}$$

where the parameter s_i can be interpreted as firm i's holding of share catch quotas, or its allocated share of total catches the industry is expected to choose. This catch shareholding is defined as $s_i = \hat{h}_i/\, \hat{h}$ where $\hat{h}_i$ is the individual catch quota and $\hat{h}$ is the Total Allowable Catch quota. Moreover, when $\sum s_i = 1$ is the total supply of shares in the market and all firms are price-accepting agents in the share market then $h = h_i/s_i = \sum h_i$.

In this two-stage sequential mechanism, in the second stage firm *i* chooses catches h_i according to

$$V(s_i) = \max_{h_i} \{\pi_i(h_i, s_i) = B_i(h_i) - s_i D(h_i, s_i)\} \tag{12}$$

where $V(s_i)$ is the value of share holding s_i. The necessary optimality condition to (12) using (10) and (11) is

$$B_i'(h_i) = \, D_i'(h_i/s_i) \tag{13}$$

which defines $h_i = h(s_i)$. Since the objective in problem (12) is strictly concave, condition (13) is also sufficient, and the optimum is unique. In our case (12) solves to

$$h_i(s_i) = \frac{p\, r\, s_i\, x^2}{2\, p\, K + c_i\, r\, s_i} \tag{14}$$

which is the harvest chosen independent of whether the agent is a price taker or not. Equation (14) inserted into the value function (12) gives

$$V(s_i) = \frac{p^2\, r\, s_i\, x^2}{4\, p\, K\, + 2\, c_i\, r\, s_i} \tag{15}$$

Suppose the fishery comprises a large number of firms, each small enough that it is a reasonable approximation to treat them as price-taking agents in the market for shares s_i. In the first stage firm i trade catch-effort shares, solving the decision problem

$$\max_{s_i} \{ V(s_i) - \theta(s_i - \tilde{s}_i) \} \tag{16}$$

where θ is the market-clearing price per unit of s_i, $\tilde{s}_i$ is the amount of share quotas initially allocated to firm i (e.g. through Grandfathering). The sum of allocated and of selected individual share quotas both satisfies the condition $s = \sum \tilde{s}_i = \sum s_i = 1$.

The necessary optimality condition for interior solutions of (16) is $\theta = V'(s_i)$, which, by the Envelope Theorem applied to (16), is equal to

$$\theta^* = \theta = V'(s_i) = \frac{h_i}{s_i} D'\left(\frac{h_i}{s_i}\right) - D\left(\frac{h_i}{s_i}\right) = \frac{p^3\, K\, r\; x^2}{(2\, p\, K + c_i\, r\, s_i)^2} \tag{17}$$

Here the (one) asterisk superscript denotes the full competition price. This price is positive since all parameters are positive. Since $V''(s_i) < 0$ [1] it follows that the objective in problem (16) is strictly concave. Hence, condition (17) is both necessary and sufficient, and the optimum unique.

The price θ is equal for both firms, so we can solve an equation system with (17) for *i*=1,2 and with the constraint $s_1 + s_2 = 1$:

$$\left.\begin{aligned} \theta^* &= V'(s_1) \\ \theta^* &= V'(s_2) \\ s_1 + s_2 &= 1 \end{aligned}\right] \tag{18}$$

which yields solutions

$$\left.\begin{aligned} s_1 &= \frac{c_2}{c_1 + c_2} \\ s_2 &= \frac{c_1}{c_1 + c_2} \\ \theta^* &= \frac{(c_1 + c_2)^2 p^3\, K\, r\, x^2}{(2\,(c_1 + c_2)\, p\, K + c_1\, c_2\, r\,)^2} \end{aligned}\right] \tag{19}$$

Total costs under flexibility with a competitive share market are found by inserting (14) into the cost function, and then (18), with the result given by

$$TCF^* = \sum_{i=1,2} (c_i/2)(h_i/x)^2 = \frac{c_1\, c_2\, (c_1 + c_2)\, p^2\;\, r^2\, x^2}{2\,(2\,(c_1 + c_2)\, p\, K + c_1\, c_2\, r\,)^2} \tag{20}$$

This TCF^* expression (20) (Total Costs with Flexibility) will be compared with the expression for TCF^{**} below (33) which denotes total costs with flexibility when market power is present.

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[1] $V''(s_i) = -D''\left(\frac{h_i}{s_i}\right)\frac{h_i^2}{s_i^3} = -\frac{2\, c_i\, (p\, K\,)^3\, r^2}{(2\, p\, K + c_i\, r\, s_i)^3}$

4. Flexibility and imperfect share markets

Share quotas and catches

The previous assumption that all firms exhibit price taking behaviour in a share market with a fixed supply may sometimes be a reasonable approximation. The suggested implementation might, however, also be useful if firms were allowed to exercise market power. It is a fact that strategic behaviour might lead to inefficiencies in any market with a uniform price. Nevertheless, given the same initial distribution of permits, losses due to market power can be lower with our system compared to the levels that for instance, Helgesen (2022), Hahn (1984) and Westskog (1996) predict for the traditional transferable quota system (ITQ). A simple argument supporting this view is that the competitive fringe of firms in our regime has the option to utilize the flexibility of the system for their own benefit. This option might be used in following way:

Proposition 1

If the price of share quotas is higher (lower) than in competitive equilibrium, a traditional price-taking firm in the share market will buy a lower (higher) amount of share quotas than the amount that corresponds to the quantity it chooses to catch.

Proof: For all firms, the condition $B_i'(h_i) = D_i'(h_i/s_i)$ (13) implicitly defines a harvest reaction function (14). Differentiation of this function with respect to s_i as well as manipulation to obtain the elasticity of with respect to h_i yields

$$El_{s_i}(h_i) = \frac{s_i}{h_i} h_i{}'(s_i) = \frac{D_i''(h_i/s_i)}{D_i''(h_i/s_i) - s_i B_i''(h_i)} \tag{21}$$

Since $D_i'' > 0$ and $B_i'' < 0$, the elasticity $El_{s_i}(h_i)$ is always less than one. Hence, the harvest level is relatively inelastic with respect to a change in the shareholding. Because a competitive firm only buys more share quotas than the amount that corresponds to what it catches when the price is lower than in competitive equilibrium and vice versa, the desired assertion follows. QED.

As explained by Helgesen (2022) and Hahn (1984), a dominant buyer (seller) of permits in a traditional quantity system may find it profitable to understate (overstate) his demand in order to force down (up) the price of quotas below (above) the competitive price. Relative to a conventional system that undertakes a one-to-one relationship between individual harvests and quotas, a competitive fringe that behaves as predicted by Proposition 1 is less inclined to sell share quotas at low prices, as well as less inclined to buy share quotas at high prices. The strategic firm anticipates this and will comparably lower its tendency to understate (overstate) demand in the first place. Hence, a dominant firm's manipulation efforts within the proposed scheme can only be less successful.

The competitive fringe and the leader

Since the members of the competitive fringe behave as price-taking agents, their result is equivalent to the case of perfect competition and they can all be represented by a representative agent with index i=F with the mean cost function $C_F(h_F) = \left(c_F/(2\,x^2)\right)h_F^2$, where $c_F = (\sum_{i=2}^{n} 1/c_i)^{-1}$. The mean cost function of the leader i=L is similar, $C_L(h_L) = \left(c_L/(2\,x^2)\right)h_L^2$. The fringe's and the leader's harvest function is for both given by (14)

$$h_i(s_i) = \frac{p\,r\,s_i\,x^2}{2\,p\,K + c_i\,r\,s_i} \tag{22}$$

but s_i's here will depend on the share price θ that may be different from the price (19) when there is full competition in the share market. The same is the case for the value function (15), repeated here

$$V(s_i) = \frac{p^2\,r\,s_i\,x^2}{4\,p\,K\ + 2\,c_i\,r\,s_i} \tag{23}$$

Share quotas for the competitive fringe are determined by the corresponding decision problem as (16)

$$\max_{s_F}\{V(s_F) - \theta(s_F - \tilde{s}_F)\} \tag{24}$$

where θ is the price that may be manipulated by the leader in this imperfect market and $\tilde{s}_F$ is the initial share grandfathered to the fringe. The connection between quota price and chosen share quantity s_F of the fringe is again found by the Envelope Theorem,

$$\theta^{**} = \theta = V'(s_F) = \frac{p^3\,K\,r\ \,x^2}{(2\,p\,K + c_F\,r\,s_F)^2} \tag{25}$$

The leading firm (with index i=L) have another formulation of its decision problem. It optimizes its profit with s_L as the control variable, and as indicated, is θ a function of s_L. Additionally, the formulation includes a condition that the market for share quotas needs to balance out

$$\max_{s_L}\{V_L(s_L) - \theta(s_L)(s_L - \tilde{s}_L)\}\ s.t.\ s_L = 1 - s_F \tag{26}$$

The latter formulation (26) yields the following first order condition for L

$$V_L'(s_L) + \theta'(s_L)(\tilde{s}_L - s_L) - \theta(s_L) = 0 \tag{27}$$

By inserting the constraint in (26) into (25) we find $\theta(s_L)$ as

$$\theta^{**} = \theta(s_L) = V'(1 - s_L) = V'(s_L) = \frac{p^3 \, K \, r \;\, x^2}{\left(2 \, p \, K + c_F \, r \, (1 - s_L)\right)^2} \tag{28}$$

and thereby also $\theta'(s_L)$ as

$$\theta'^{**} = \theta'(s_L) = V''(s_L) = \frac{2 \, c_F \, p^3 \, K \, r \;\, x^2}{\left(2 \, p \, K + c_F \, r \, (1 - s_L)\right)^3} \tag{29}$$

while $V'(s_L)$ is derived from (23) as

$$V'(s_L) = \frac{p^3 \, K \, r \;\, x^2}{(2 \, p \, K + c_L \, r \, s_L)^2} \tag{30}$$

The resulting equation (27), with the input of (28), (29) and (30), becomes a complicated expression in s_L and $\tilde{s}_L$ of order 3. The First Order Condition (FOC) is

$$\text{FOC} = -((K \, p^3 \, r^2(-6 \, c_F^2 \, K \, p \, r(-1 + s_L)^2 + c_F^3 \, r^2(-1 + s_L)^3 + 2 \, c_L \, Kp \, s_L \, (4 \, K \, p + c_L \, r \, s_L) + c_F \, (4 \, c_L \, K \, p \, r \, s_L \, (1 + s_L - 2 \, s_L^0) + c_L^2 \, r^2 \, s_L^2 \, (1 + s_L - 2 \, s_L^0) + 8K^2 p^2(-1 + 2 \, s_L - s_L^0)))x^2)/((2 \, K \, p - c_F \, r(-1 + s_L))^3 (2 \, K \, p + c_L \, r \, s_L)^2)) = 0 \tag{27.b}$$

This equation (27.b) (FOC=0), solved with respect to s_L have three roots of which only one root is real.

The efficiency TCF^{**} (Total Costs with Flexibility) in this case is given by

$$TCF^{**} = \sum_{i=F,L} (c_i/2)(h_i/x)^2 \tag{31}$$

where h_F og h_L is given by (14), which again need input of s_F and s_L. The share s_F is found as the positive root in solving (25)

$$s_F(\theta) = \frac{\sqrt{K} \, p^{3/2} \sqrt{r} \, x - 2 \, K \sqrt{\theta} \, p}{c_F \, \sqrt{\theta} \, r} \tag{32}$$

while s_L is given by the real root of (27).

$$\Delta TCF = 100 * \frac{TCF^{**} - TCF^*}{TCF^*} \tag{33}$$

In the numerical illustration below ΔTCF will be compared with the efficiency loss ΔTC with market power in the case of traditional ITQs.

Traditional ITQ's

With the traditional case the model is structured as a two stage Stackelberg game where market power only may arise in the quota market, i.e. we assume all firms take the price for fish for granted (Helgesen, 2022). The game is solved with backward induction. First the market leader (L) chooses either the harvesting level or the quota price that maximizes their profits. The competitive fringe (F) then takes the quota price as given and maximizes profits with respect to their harvesting levels. Costs are given by

$$C_i(h_i) = (c_i/2)(h_i/x)^2 \tag{34}$$

and we assume that all firms comply with their quota, i.e. that $h_i = q_i$ for $i = F, L$.

In the second stage, the competitive fringe maximizes individual profit.

$$\max_{h_F} \{\pi_F(q_F) = p\, q_F - C_F(q_F) - m(q_F - \tilde{q}_F)\} \tag{35}$$

where m is quota price and $\tilde{q}_F$ is its initial allocation. Then (35) solves to

$$q_F = \frac{x^2}{c_F}(p - m) \tag{36}$$

In the first stage, the leader maximizes profits with respect to the quota price (or its harvesting level), the reaction function of the follower and is subject to the residual demand, which, in this case, is equivalent to the market clearing constraint.

$$\max_{q_L} \{\pi_L(q_L) = pq_L - C_L(q_L) - m(q_L)(q_L - \tilde{q}_L)\}\ s.t.\ q_L = Q - q_F \tag{37}$$

where Q is the TAC. Using q_L as the control variable the first order condition is

$$\text{p} - C_L'(q_L) - m(q_L) - m'(q_L)(q_L - \tilde{q}_L) \tag{38}$$

Solving (38) with respect to the quota price m and using the constraint in (37) yields

$$m = p + \frac{c_F(c_F \tilde{q}_L - (c_L + c_F)Q)}{(c_L + 2\, c_F)x^2} \tag{39}$$

which again when set into (36) yields

$$q_F = \frac{-c_F\ \tilde{q}_L + (c_L + c_F)Q}{(c_L + 2\, c_F)} \tag{40}$$

and

$$q_L = Q - q_F = \frac{c_F\ (\tilde{q}_L + Q)}{(c_L + 2\, c_F)} \tag{41}$$

5. Numerical illustrations of marketpower

In the following illustrations the results of our proposal will be compared with traditional transferable quota regulation (Helgesen, 2022). The numerical illustrations are based on data from an effort regulated bottom trawl fishery in the North Mediterranean Coast. For our purpose we assume that the fleet will be quantity regulated and that individual vessels are owned by two firms (Firm L and F) having homogeneous cost functions. In one case there is no market power present, while in the other case firm L have market power while firm F is the competitive fringe. The parameter values for the two fleets are reported in table 1.

Table 1: Parameters for the NW Mediterranean demersal fishery exploited by otter bottom trawl

Fleet size (2019)	578	Vessels
Individual effort level (number of fishing days)	120 -190	days / year
Mean individual effort (number of fishing days)	155	days / year
Harvest	10,640	tonnes
Harvest at MEY	11,830	tonnes
Biological production function (Schaefer model)		
K	19,900	tonnes
r	2.5	
q = 0.00397 (tonne/year)/155 =	2.56 10^{-5}	tonnes/day
x = equilibrium stock size at MEY	12,148	tonnes
Economic parameters		
Price of fish	9,472,5	€/tonne
Total cost per unit effort	1066.7	€/day
Total quadratic costs 1066.7/38021	0.0281	$(€/day^2)$.

Based on STECF (2020); Gómez and Maynou (2020).

Through the equation

$$\theta^{**} = \theta(s_F) = V'(s_F) = \frac{p^3\, K\, r\; x^2}{\left(2\, p\, K + c_F\, r\, (1 - s_L)\right)^2} \tag{28}$$

we find the price θ^{**} as a function of s_F for the case of flexible quotas, while for the traditional case price is given by

$$m = p + \frac{c_F(c_F\, \widetilde{q}_L - (c_L + c_F)Q)}{(c_L + 2\, c_F)x^2} \tag{39}$$

Figure 1 shows the prices for both cases as a function of its initial (grandfathered) allocation $\tilde{s}_L$. At $\tilde{s}_L = 0.5$ we find the free competition prices. In the traditional quota case (red curve) (41) that price is 7380 € for each unit of the share-quota. Likewise, the price curve (blue) in the flexible case is determined by (28) where s_L as a function of $\tilde{s}_L$ is the real root solution of the third order equation (27,b). The free competition price is here equal to 3544 € for each unit of the share-quota. The lower quota prices observed in the flexible case, relative to the traditional case, result from the fact that the flexibility scheme imposes a tax on firms.

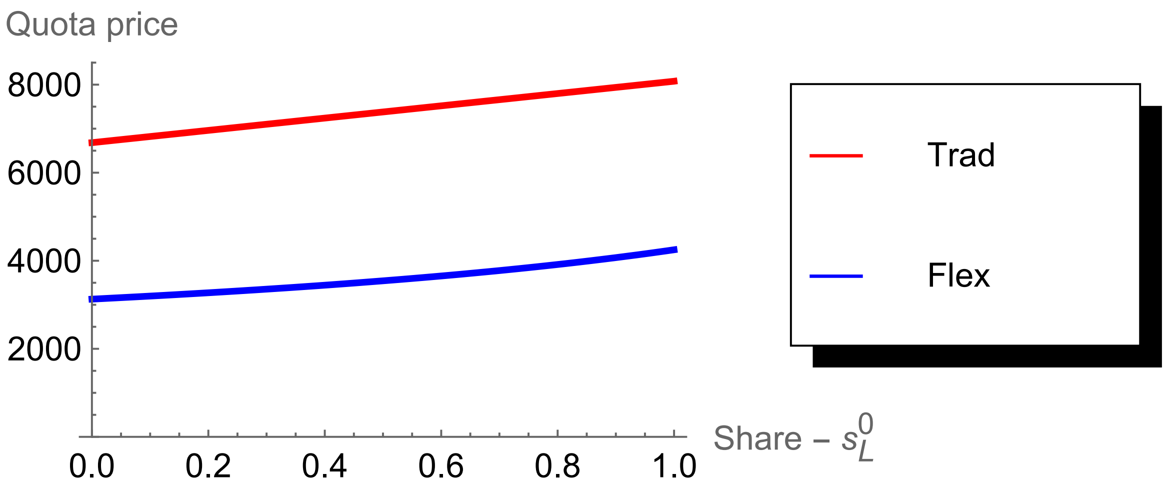

Figure 1. Share-quota price as a function of initial share of the leading firm. Difference due to tax payment.

Figure 2 shows the leader's final choice of share-quota s_L as a function of $\tilde{s}_L$, its initial (grandfathered) allocation, in the traditional case (41) (red) and in the flexible case (blue) where the curve is determined by the real root of the third order equation (27b). We can see the flexible system slightly improves the quota share choices. At $\tilde{s}_L = 0$ the leader will act as a monopsonist that push prices below competitive level by buying less shares s_L. With traditional control $s_L = 0.333$ while with flexibility $s_L = 0.354$. At $\tilde{s}_L = 1$ the leader will act as a monopolist that want to drive prices up from the competitive level by selling less shares s_L. With traditional control $s_L = 0.667$ while with flexibility $s_L = 0.696$.

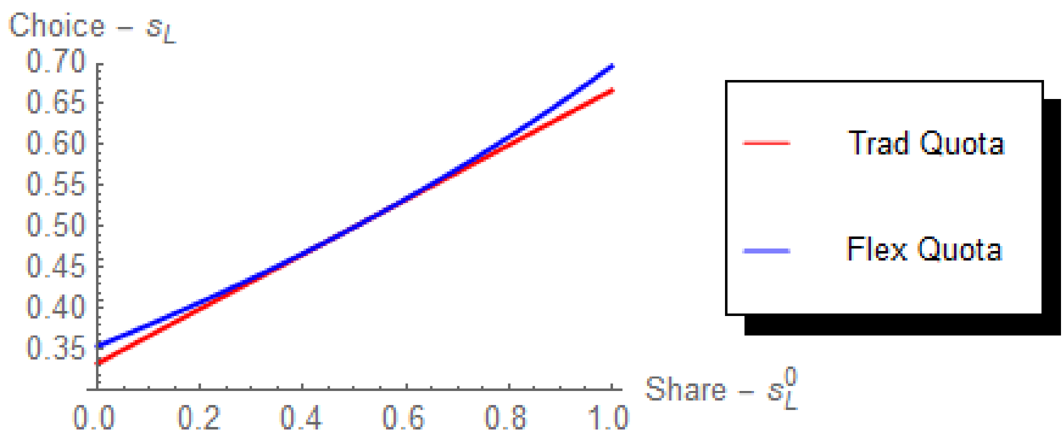

Figure 2. Final choices of shares s_L as a function of leader's initial (grandfathered) allocation. Crossing takes place at the full competition point $(0.5, 0.5)$.

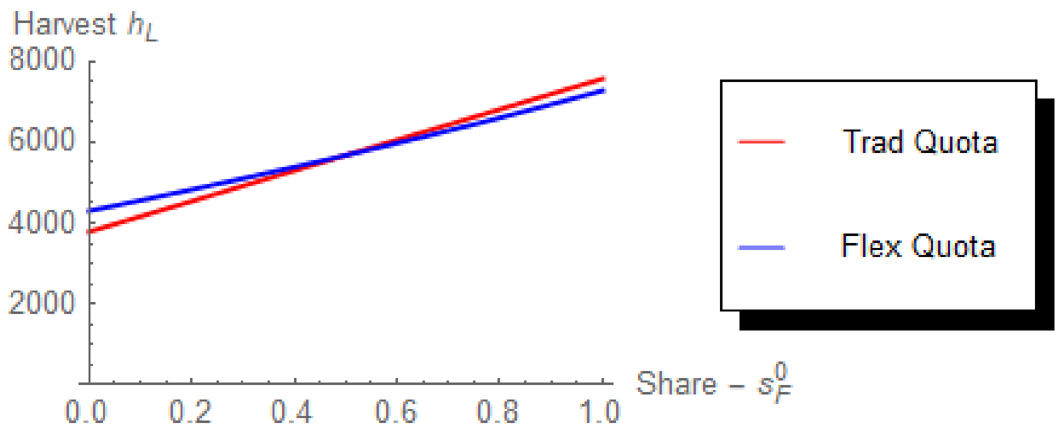

Figure 3. The leader's final choice of harvest h_L as a function of the fringe's initial (grandfathered) allocation. Crossing takes place at the full competition point $(0.5, 5681)$.

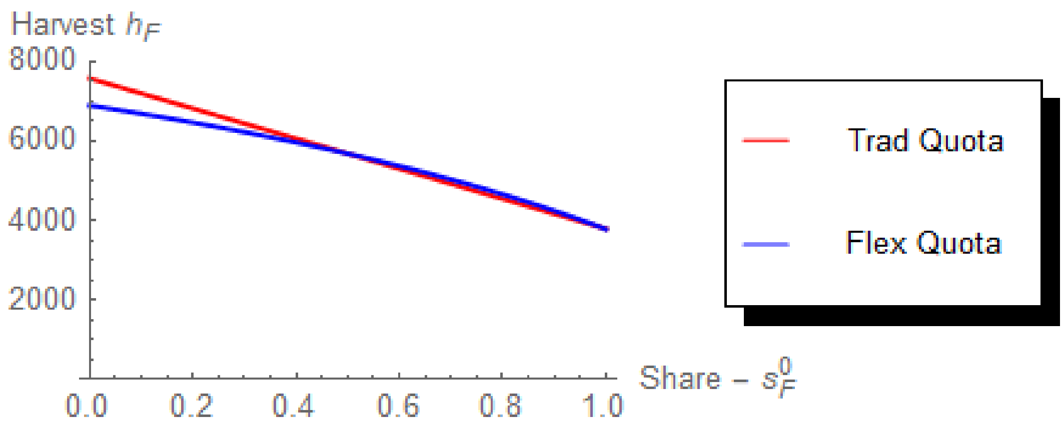

Figure 4. The fringe's final choice of harvest h_F as a function of its initial (grandfathered) allocation. Crossing takes place at the full competition point $(0.5, 5681)$.

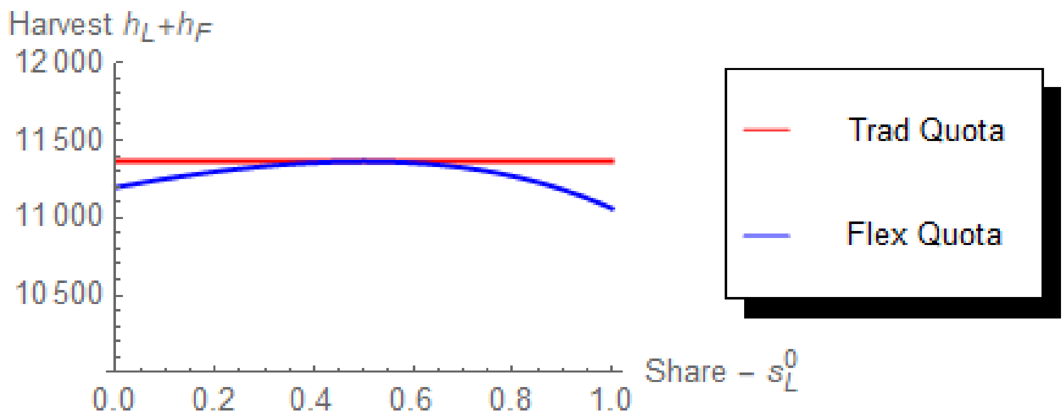

Figure 5. Total choice of harvest $h_L + h_F$ as a function of the leaders initial (grandfathered) allocation. The full competition point $(0.5, 11363)$.

The competitive fringe's (Firm F) choice of harvest h_F as a function of the fringe's initial (grandfathered) allocation. Crossing takes place at the full competition point $(0.5, 5915)$

With perfect competition equation (36) applies both for (F) and (L). Total costs are

$$TC^* = (c_L/2)(h_L/x)^2 + (c_F/2)(h_F/x)^2 = \frac{c_L\, c_F\, Q^2}{(c_L + c_F)x^2} \tag{42}$$

Using (41) and (40) yields a similar expression for total costs (TC^{**}) in case of market power for (L). As a percentage increase in total cost, the efficiency loss caused by market power is expressed as

$$\Delta TC = 100 * \frac{TC^{**} - TC^*}{TC^*} = 100 * \frac{c_F\left((c_L + c_F)\,\tilde{q}_L - c_F\, Q\right)^2}{c_L\,(c_L + 2\,c_F)^2\, Q^2} \tag{43}$$

where $\tilde{q}_L$ is better replaced by $\tilde{q}_L = Q\,\tilde{r}_L$, introducing $\tilde{r}_L$ as L's initial (grandfathered) share of the total quota. The minimum of ΔTC with respect to $\tilde{r}_L$ is found by the first order condition $d\Delta TC/d\tilde{r}_L \ = 0$ which solves to

$$\tilde{r}_L \ = \frac{c_F}{(c_L +\ c_F)} \tag{44}$$

Figure 6 shows the percentage efficiency loss for the trawler fleet with parameters from table 1. The red curve shows efficiency loss ΔTC of the "traditional quota" while the blue curve shows efficiency loss ΔTCF of the "flexible quota" which is calculated from the real root of equation (26). With flexibility the efficiency loss appears to be negative when $\tilde{s}_L$ deviates from 0.5. With reference to figure 5: this is caused by total costs becoming lower as harvest quantity diminishes.

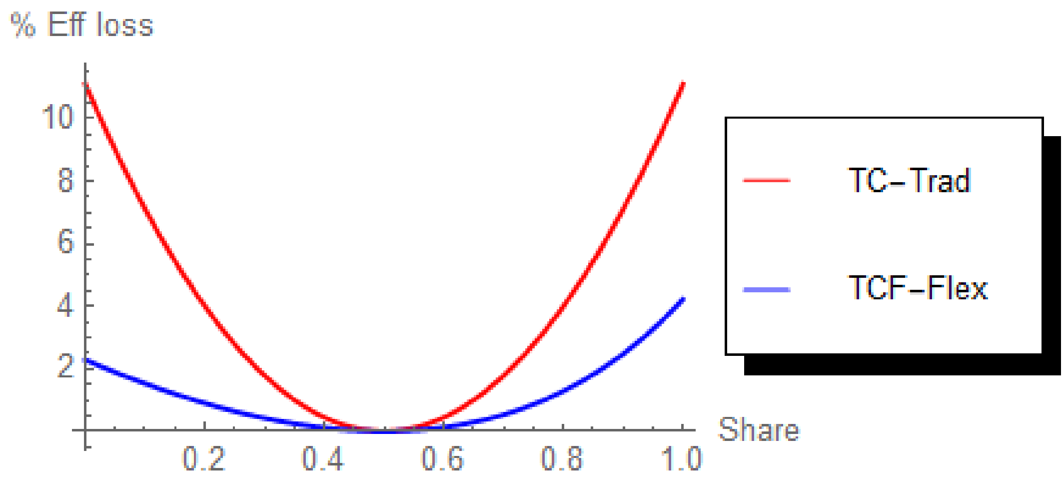

Figure 6. Total efficiency loss as a function of the leader's initial (grandfathered) allocation with the traditional and the flexible quotas

However, as can be seen in figure 5, the harvest outcome differs for the two quota systems. Hence, making a fair comparison would imply that harvest outcomes are the same. In figure 7 this difference is corrected, by adjusting output of the traditional quota system. We can observe that the small correction does not make any serious difference to figure 6.

Another observation: the efficiency improvement of between 3-5 times (figures 6 - 7) by switching from traditional quotas to the flexible quotas seems to be fundamental.

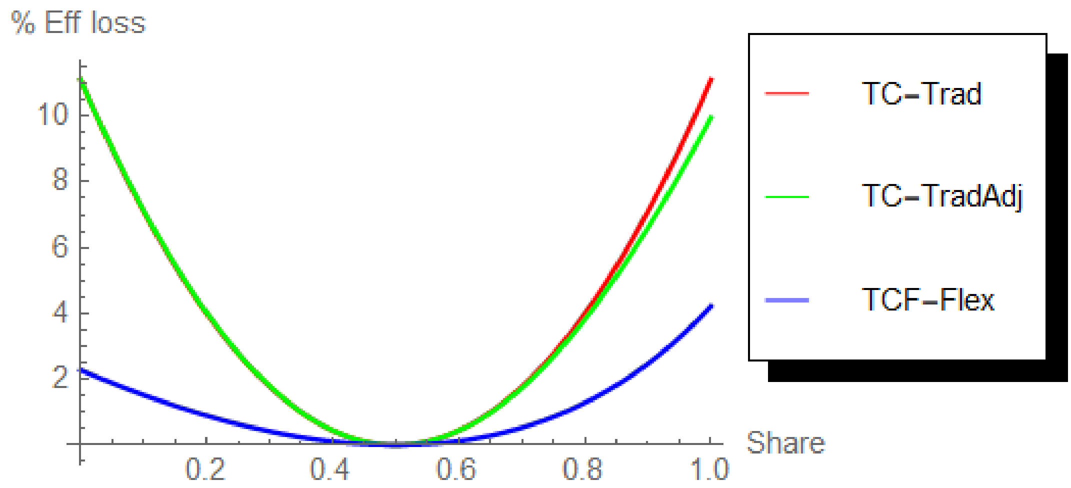

Figure 7. Total efficiency loss as a function of the leader's initial (grandfathered) allocation with the traditional and the flexible quotas. The green curve shows the case when there are no differences in output (ref figure 5) between the systems.

6. Discussion

This paper suggests a simple catch management scheme (in section 3) for fisheries that turns out to be efficient when we employ the logistic Gordon-Schaefer model (Schaefer, 1957). With that model, management measures can be interpreted in the context of benefit (9) and damage functions (10). In more advanced fishery models, the principles of this scheme, about implementing a combination of a subsidy (benefit for catches when no other participate in the fishery) and a quadratic tax (to compensate for fishing mortality or stock damage) into a function that is strictly concave, may still be operational. However, a too complicated fishery model exposed to fishers may be unfortunate. Just like the advantage of representing complex fishery management recommendations by suggesting Total Allowable Catches (TAC's) for each species, it might be more favourable to employ the suggested quadratic scheme for each species. The scheme happens to be optimal (with the logistic Schaefer model) and provides an easily computable (and understandable) linear subsidy ($R_i(h_i) = p\, h_i\, K/x$) and quadratic tax function (11) expression.

The practical advantage of the proposal, compared to the traditional quantity control, is that its flexibility may make it easier for fishing vessels to comply with regulations while inefficiencies caused by power in the quota market might be significantly reduced, It has advantages, for instance, in cases where weather conditions at the end of the fishing season make it profitable to go for more daytrips, or if bad weather conditions result in fewer daytrips.

Moreover, more efficient fishers might choose higher quantities of catches than the less efficient participants.

In chapter 4, we investigate how the suggested control system may work in the case of strategic behaviour in the quota market. Like Hahn (1984) we assume the existence of many price-taking firms (referred to as the competitive fringe) and of one leading firm that is able to choose its quota share and thereby indirectly the quota price using strategic considerations. As basis for the outcome are the initial quotas for the fringe (F) and the leader (L). In figure 7 we can see that the efficiency loss using the flexible system is 5-6 times lower, i.e. a significant reduction.

This research may be extended in different ways. An obvious extension would be to formulate a dynamic model which may also allow for quota transfers between periods, as is common in many fisheries. Another possibility is to include more than one species, initially in a static model, where quota transfers between fisheries might be possible. Starting with the static model presented in this article, a stochastic version of the growth function might also be considered. These extensions would enhance the practicability of this modelling approach for practical fisheries management.

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In this article we show benefits of quota flexibility in a single-stock fishery model where one of the firms is allowed to behave strategically in the trading of quotas while other firms in the fishery are price takers. The ex-vessel price for fish is assumed constant. Quota flexibility is implemented through a settlement at the end of each regulation period. In that settlement firms having unused quotas are compensated by a subsidy, while those who have quota shortfalls are obligated to pay a tax. For the same deviation the tax is higher than the reward. Former literature shows that market power under a traditional ITQ system can lead to inefficiencies. However, losses due to market power can be subdued when quotas are more flexible. A simple argument to account for this view is that the competitive fringe of firms in the flexible case have the option to make use of the tax/reward system. Thus, rather than being exploited by the price manipulating firm the competitive fringe might find it better to deviate from the 1:1 "quota — realized catches"- relationship that characterizes competitive equilibrium.

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