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Bycatch ITQ Management in Oligopolistic Fisheries

Jean-Christophe Pereau[*] Nicolas Sanz[†]

Abstract

This paper analyzes the effects of an individual transferable quota (ITQ) system implemented on bycatch on the global harvest level of oligopolistic fisheries. We show that the impact of changes in the total allowable catch (TAC) on the equilibrium harvest level depends on the degree of returns to scale in harvest. In particular, a reduction in the TAC may lead to a rise in activity in fisheries characterized by some amount of increasing returns to scale. Besides, these effects appear to be stronger, the fiercer the competition within fisheries.

Keywords: Oligopolistic competition; Fisheries; Bycatch ; ITQs.
JEL Classification: Q21, Q22, D43

1 Introduction

As Davies *et al.* (2009) point out, “one of the most urgent threats to the world’s remaining fish stocks is commercial fishing, especially the indiscriminate capture of non-target organisms, typically referred to as "bycatch". [...] Bycatch is so pervasive that it spans the spectrum of marine fauna and fishing gear including turtles on hooks, juvenile fish in nets, and benthic invertebrates in trawl and dredge gear. The role of bycatch in degrading marine ecosystems has made this one of the most significant nature conservation issues in the world today, with serious food-security implications for up to 1 billion people who depend on fish as their principal source of protein.”. According to the definition retained by Davies *et al.* (2009), bycatch

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represents 40.4 percent of global marine catches, exposing systemic gaps in fisheries policy and management[1].

In order to deal with the above phenomenon, the Individual Transferable Quotas (ITQ) management system is nowadays used in many fisheries. It has indeed revealed to be a useful tool to limit the harvest of target species that are threatened by economic activities and to avoid their over-exploitation (Boyce, 1996). But it has also been used since several years to control bycatch itself (see *e.g.* Diamond, 2004, for a study on four protected species). Under an ITQ system, the total allowable catch (TAC) set by the regulating agency is divided into individual quota rights of harvesting among fishers. The obligation of holding ITQs to be allowed to harvest appears to provide efficient economic incentives. These incentives promote, in turn, an efficient resource use by ensuring that the TAC will be harvested at the minimum possible cost (Clark, 1990). As noted by Bjorndal and Gordon (1993), "*transferability of current boat quotas may improve flexibility and efficiency through its potential reduction of harvesting costs*". During the last decades, the implementation of quota markets in numerous fisheries by significant fishing nations has thus generated rather positive results, allowing for the conservation of many species that were previously on the way of extinction.

Nevertheless, under a pure economic viewpoint, ITQ management policies compel firms to bear additional costs, which can prove harmful for the activity of imperfectly competitive fisheries, within which firms might be induced to increase their price while reducing their harvest level. Thus, at the level of the whole fishery, the implementation of an ITQ system might lead to a rise in the aggregate fish's price and hence, to a fall in the levels of global demand and activity. Such an environmental tool could thus finally reveal to be economically inefficient.

The nature of the competition at stake in the fish market seems indeed to play an important role in the determination of the equilibrium level of global harvest, as suggested by the works of Bjorndal *et al.* (1993b, this Journal). Fisheries are often made up of a limited number of large fishing firms that use big boats during fishing campaigns. Besides, several studies concerning the formation of the fish's price suggest to consider price making firms (see *e.g.* Bjorndal, 1993). Lastly, the analysis of the supply side of the fish market seems to be of particular importance since the literature on fisheries economics only contains few studies on how it really behaves economically though Nøstbakken and Bjørndal (2003) note that "*from the perspective of market analysis, knowledge about the supply function is essential*". As far as quota markets are concerned, a competitive ITQ management system seems

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[1] "Bycatch is catch that is either unused or unmanaged".

to be capable of producing the optimal level of catch in a fishery provided that a market exists for each quota (Boyce, 1996).

Although the effects of ITQ management systems on the biomass evolution have been deeply analyzed in the biological litterature, their impact on the economic activity of fisheries have been much less studied. This paper tries to partly fill this gap by analyzing the consequences of the implementation of an ITQ market for controlling bycatch on the global harvest level of fisheries. In order to do so, we develop a general equilibrium model of a fishery in which the fish market is oligopolistic whereas the ITQ market is perfectly competitive. Our paper then clearly analyzes the price setting behaviour of fishing firms that may indeed be willing to pass the ITQ costs they bear on to their output price and the consequences of such a behaviour for the global harvest level of fisheries. Moreover, our framework enables to study the effects of the fish market structure itself on the efficiency of the ITQ management system.

This paper is organized as follows. Section 2 presents the demand and supply sides of the fish market and the ITQ magement system that the regulating agency implements in order to control bycatch within the fishery. Section 3 derives the global equilibrium of the fishery, coming from the optimization of their profit by oligopolistic fishing firms that face technical and demand constraints. Section 4 studies the consequences of changes in the TAC on the equilibrium level of global harvest with respect to the scope of the returns to scale the fishery exhibits. Finally, section 5 gives some concluding remarks and suggests some possible extensions of the model.

2 An economic model of fisheries

We begin our analysis by presenting the demand and supply sides of the fish market and the regulating agency. For the sake of clarity, we voluntarily ignore the pure biological features characterizing the working of fisheries to concentrate on their economic properties. Since the analysis deals with the behaviour of fishing firms over a short period of time, the number of fishing firms, the capital they use to harvest, and the size of the fish stock are supposed to remain fixed.

2.1 The demand for fish

The fish market demand function is assumed to be isoelastic and given by:

$$H^d = P^{-\varepsilon} \tag{1}$$

where H^d stands for the demand the fishing industry faces and P, the aggregate price level within the industry. The parameter ε ($\varepsilon > 1$) denotes the price elasticity of demand. Competition within the fishery thus becomes perfect when ε tends to infinity.

2.2 The supply of fish

We assume that the fishery is made up of n identical fishing firms competing to supply a homogeneous product in an industry. Let $H = \sum_{i=1}^{n} H_i$ represent industry output, H_i being the output of the ith firm.

2.2.1 The harvest function

Firm i harvests an amount H_i of an homogenous target species according to the following modified Schaefer Cobb-Douglas harvest (production) function:

$$H_i = Z_i E_i^{\alpha} S^{\beta} \tag{2}$$

This function shows that H_i depends on a catchability variable, Z_i ($0 \leq Z_i \leq 1$), firm i's harvesting effort level, E_i, and the stock size of the target species, S. The variable Z_i represents the technology used for fishing and can for instance be interpreted as a measure of the tightness of the fishnet's mesh used by fishers during the fishing campaign. The extreme case $Z_i = 1$ corresponds to the legal constraint set by the regulating agency for the minimum size of the net's mesh. In our case, it is the benchmark technology for fishing but not the less harmful one as far as the resource is concerned. A lower Z_i means that fishers use a mesh with larger holes that let more potential bycatch escape. Hence, this kind of technology ensures a better sustainability of the resource since it allows a higher part of the young population to reach sexual maturity. These two extreme cases correspond to both kinds of selectivity combination, perfect and knife-edge selectivity (Clark, 1990). The variable E_i may be an aggregate of the inputs used by firms, like the amount of labor, the number of vessels or the fish season length. Since we assume that the kind of fisheries studied in this paper is unregulated and characterized by open access, stock size, S, enters into the profit function as a fixed factor, and stock dynamics are not explicitly considered, as in Bjorndal (1987)[2]. Furthermore, we also adopt, as Bjorndal

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[2] For an example of a dynamic model based on the optimization of an intertemporal profit function by a sole owner, whose objective is to maximize the present value of net revenues from a fishery, see Bjorndal (1987). For complete bioeconomic models, taking the population dynamics explicitly into account, see Bjorndal (1988) and Conrad and Bjorndal (1991).

and Gordon (1993), the usual assumption according to which boat catches do not alter the aggregate fish stock, which therefore enters the harvest function as an exogenous variable. This is equivalent to suppose that the stock size remains constant in any given year and available for exploitation. At last, the parameters α and β respectively denote the harvest elasticity with respect to the effort and the stock levels. Since the stock level is supposed to remain fixed, the degree of returns to scale corresponds to the sole effort output elasticity. As it will be shown later, the value of the parameter α will play an important role in our analysis.

2.2.2 The bycatch function

While harvesting the target species, firms simultaneously catch an amount Y_i of another homogenous species according to the following "damage" function[3]:

$$Y_i = bZ_i^{\sigma} H_i \tag{3}$$

The amount of bycatch is logically an increasing function of the catchability variable, Z_i, and of the total amount of harvest, H_i. The parameter b describes exogenous environmental shocks. Lastly, the parameter σ ($\sigma > 0$) denotes the elasticity of the amount of bycatch with respect to the catchability variable. For a given level of harvest, the higher σ, the more sensitive is the amount of bycatch with respect to changes in the catchability variable. We assume here that bycatch represents either individuals of the target species that are unmarketable because of their size, condition, sexe, age, or any other reason, and thus either discarded dead or released alive ("target bycatch"), or individuals of other species ("non-target bycatch")[4]. The first part of the above definition implies that bycatch cannot be sold in a secondary fish market and we also suppose that the environmental agency forbids the sale of the non-target bycatch for environmental reasons. This simplifying assumption

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[3] Here, bycatch represent young and little fishes that are caught when using (too) little net meshes. In the case of forage fisheries, Y_i would alternatively denote all other species (especially the biggest ones) that are simultaneously captured with (small) forage fish. Lastly, in some other fisheries, older fishes are the most fecund ones and may alternatively be the focus of conservation efforts (*e.g.* the pacific halibut or the Gulf of Mexico reef fish). Although bycatch often entails different species, we focus the analysis on the species that is mainly caught with the target one due to the particular technology used in harvest or physical similarities, for the sake of clarity. This assumption corresponds to numerous examples, as the Gulf of Gascogne langoustine fishery in France, where the hake constitutes the main species entailed in bycatch, and the shrimp trawl fisheries, in which no other potential target species are present except red snappers.

[4] For a technical survey on bycatch *per se*, see Hall (1996).

enables to ignore the determination of a bycatch's price[5].

2.3 The regulating agency

In order to focus the analysis on the bycatch species, we assume that the sustainability level of the target species is ensured. However, we assume that bycatch mainly entails another species that needs to be protected. Hence, without any regulation policy, the harvest of bycatch might be too high and might generate damages for the resource (*i.e.* $Z_i = 1$). In order to limit the use of harmful harvest technologies, the regulating agency introduces a perfectly competitive ITQ market and sets a total allowable catch (TAC) for the amount of bycatch, $\overline{Q}$[6]. We assume that the initial allocation of ITQ is free (for example, based on grandfathering or gifts), so that $\overline{Q} = \sum_{i=1}^{n} \overline{Q}_i$, and that $\overline{Q}_i$ corresponds to firm i's initial endowment of ITQ. The distribution of ITQ across fishing firms is egalitarian so that each fisher is allowed to harvest the same amount of bycatch $\overline{Q}/N$. We further suppose that ITQs are divisible and transferable and that they can be freely traded on a secondary market (see Arnason, 1990). However, we assume that intertemporal trade (*i.e.* banking and borrowing) is not allowed. Let us denote Q_i, the number of ITQ hold by firm i after trade. Consequently, $Q_i - \overline{Q}_i > (<)\ 0$ means that firm i has bought (sold) some ITQ. We finally suppose that each firm chooses conformity: it buys the quantity of ITQ that exactly covers the amount of bycatch it harvests. The compliance constraint thus reads:

$$Y_i = Q_i \tag{4}$$

By definition, the ITQ market clears if:

$$\overline{Q} = \sum_{i=1}^{N} Q_i \tag{5}$$

According to the ITQ management system described above, firms hence face a tradeoff between capturing more fishes as a whole and pay for the corresponding number of ITQs, or using a less harmful material for the stock during harvest, for instance larger net meshes, and capturing a lower amount of protected species, thus reducing the costs induced by the ITQ system. This

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[5] The retention of the total amount of by-catch is part of the management actions that are applied to fisheries nowadays (see *e.g.* Hall *et al.*, 2000).

[6] Catch quotas may otherwise be based on *e.g.* boat size (see Bjorndal and Gordon, 1993).

kind of policy may affect the composition of the global level of harvest and therefore, the sustainability of the resource.We now turn to the determination of the economic equilibrium of the fishery.

3 Global outcome

According to the oligopolistic framework retained in our model, firm i adopts the following conjecture when choosing its level of harvest :

$$\frac{\partial}{\partial H_i}\left(\sum_{j\neq i}^{n} H_j\right) = \phi_i \tag{6}$$

The parameter ϕ_i thus reflects the extent to wich firm i takes the consequences of its output decisions on those taken by other firms into account when maximizing profit[7]. However, we suppose that firm i takes the quota price determined in the ITQ market as given.

3.1 Fish market equilibrium for a given ITQ price

In the Schaefer harvest function, the term Z_i in eq (2) is usually referred as a constant catchability coefficient. In our framework, we assume that it is a choice parameter for fishers that determines the proportion of bycatch, Y_i, next to the total amount of harvest itself, H_i. Hence, firm i maximizes the following profit function:

$$\Pi_i = PH_i - C_iE_i - MY_i \tag{7}$$

with respect to Z_i and H_i, subject to the demand, harvest, damage and compliance constraints (resp. given by eq. (1)-(4))[8]. In the profit function (7), C_i denotes the cost of effort paid by firm i and is assumed to be exogenous. We further suppose, as in Bjorndal (1987), that the fishery considered here is small with respect to all the other presumably existing ones and complementary to the latter, and that no special equipment is necessary for its

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[7] This approach reveals to be quite useful in that it allows to capture different standard cases of competition. The case of price-taking behavior with perfect competition is represented by $\phi_i = -1$, while the Cournot case corresponds to $\phi_i = 0$. In the extreme case of monopoly, $\phi_i = 0$ and $n = 1$. See for instance Sen and Dutt (1995).

[8] Profit maximization could otherwise be made with respect to the effort level, which would lead, through the combination of the firm's constraints, to the same results. For instance, the optimal vessel size in a fishery can be used as the variable input, in the spirit of Bjorndal and Gordon (1993).

working. This enables to disregard investment decisions, which are supposed to depend on other main activities in the major fisheries. The variable M stands for the nominal quota price and will be thus determined in the ITQ market (see below). Solving the system of two unknowns composed of both first order conditions respectively associated with Z_i and H_i, gives, at the symmetric equilibrium ($Z_i = Z$, $H_i = H/n$, $C_i = C$, $\phi_i = \phi$) and for a given value of the quota price, the following equilibrium value of the damage index used and the amount of fish harvested[9]:

$$Z = \left[\frac{P}{(1+\Psi)\, bM} \right]^{\frac{1}{\sigma}} \tag{8}$$

and

$$H^s = nS^{\frac{\beta}{1-\alpha}} \left(bM\right)^{\frac{-1}{(1-\alpha)\sigma}} C^{\frac{-\alpha}{1-\alpha}} \left(\frac{P}{1+\Psi} \right)^{\frac{1+\alpha\sigma}{(1-\alpha)\sigma}} \tag{9}$$

where

$$\Psi = \frac{1}{1 - \frac{1+\phi}{n\varepsilon}} \tag{10}$$

denotes the markup that firms apply over their marginal cost to set their price. The oligopolistic nature of competition within the fishery is reflected by the fact that, according to Eq. (10), $\Psi > 1$. Equation (8) indicates that the optimal damage index is increasing with the fish's price, and decreasing with the firms' markup, the damage exogenous parameter, and, logically, the quota price. Eq. (9) shows that the fish's supply always increases with the number of firms. It is an increasing (decreasing) function of the fish stock and the fish price and a decreasing (increasing) function of the damage exogenous parameter, the ITQ price, the cost of effort and the firms' markup, if $\alpha < (>)\ 1$. Eq. indicates that the markup itself decreases with n and ε and increases with ϕ. Logically, the fiercer the competition between fishing firms within the fishery, the lower the markup they can apply to their marginal cost in setting their output price.

3.2 ITQ market equilibrium

We suppose that the quota price, M, is competitively determined on the ITQ market. Inserting the optimal technology index (8) and level of harvest (9) into the damage function (3), and using the compliance constraint (4)

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[9] For the sake of clarity, we ignore multiplicative constants in α and σ.

at the symmetric equilibrium ($Q_i = Q/n$) yields the expression of the global demand of quota:

$$Q = nb^{\frac{-1}{(1-\alpha)\sigma}} S^{\frac{\beta}{1-\alpha}} M^{\frac{-[1+(1-\alpha)\sigma]}{(1-\alpha)\sigma}} C^{\frac{-\alpha}{1-\alpha}} \left(\frac{P}{1+\Psi} \right)^{\frac{1+\sigma}{(1-\alpha)\sigma}} \tag{11}$$

Inserting the demand for ITQ (11) into the equilibrium condition of the ITQ market (5) and isolating M leads to the expression of the equilibrium quota price:

$$M = b^{\frac{-1}{\Phi}} S^{\frac{\beta\sigma}{\Phi}} \left(\frac{\overline{Q}}{n} \right)^{\frac{-(1-\alpha)\sigma}{\Phi}} C^{\frac{-\alpha\sigma}{\Phi}} \left(\frac{P}{1+\Psi} \right)^{\frac{1+\sigma}{\Phi}} \tag{12}$$

where $\Phi = 1 + (1-\alpha)\,\sigma$. The price of quota increases (decreases) with the fish's stock, the number of firms, and the fish's price, and decreases (increases) with the exogenous damage parameter, the TAC level, the cost of effort and the firms' markup, if $\Phi > (<)\ 0$, *i.e.* $\alpha < (>)\ (1+\sigma)/\sigma$.

3.3 General equilibrium

Reinserting (12) into (9) finally leads to the level of fish's global supply when the ITQ market is in equilibrium:

$$H^s = n^{\frac{(1-\alpha)\sigma}{\Phi}} S^{\frac{\beta\sigma}{\Phi}} \left(\frac{\overline{Q}}{b} \right)^{\frac{1}{\Phi}} \left[\frac{P}{(1+\Psi)\,C} \right]^{\frac{\alpha\sigma}{\Phi}} \tag{13}$$

The fish's global supply function (13) depends on all exogenous variables of the model. However, the sign of these relations crucially depends on the value of Φ, which itself depends on the scope of the existing returns to scale within the fishery. As will be shown, this will have important consequences on the effects of the ITQ policy on the equilibrium level of global harvest. Before turning to this point, let us close the model with the fish's demand curve. This can be directly done by combining the demand (used at the symmetric equilibrium) and supply functions (1) and (13) and by isolating H. One finally obtains:

$$H^* = n^{\frac{(1-\alpha)\varepsilon\sigma}{\Omega}} S^{\frac{\beta\varepsilon\sigma}{\Omega}} \left(\frac{\overline{Q}}{b} \right)^{\frac{\varepsilon}{\Omega}} \left[\frac{1}{(1+\Psi)\,C} \right]^{\frac{\alpha\varepsilon\sigma}{\Omega}} \tag{14}$$

where $\Omega = (1+\sigma)\,\varepsilon - \alpha\sigma\,(\varepsilon - 1)$. Eq. (14) indicates that the equilibrium level of global harvest is unique.

We can now analyze the properties of the equilibrium level of global harvest within the fishery, in particular, its sensitivity with respect to changes in the TAC.

4 ITQ management of bycatch

We begin the analysis of the ITQ policy effects by noting that the signs of the elasticities of the equilibrium harvest level with respect to the exogenous variables of the model all depend on the sign of Ω, *i.e.* on the relative values of the structural parameters α, ε and σ.

4.1 The degree of returns to scale within the fishery

The following sub-section highlights the fact that the impact of changes in the TAC crucially depends on the scope of the economies of scale that may exist within fisheries.

4.1.1 Decreasing or "slightly" increasing returns to scale

The cases of decreasing or "slightly" increasing ($\alpha < [\varepsilon/(\varepsilon-1)](1+1/\sigma)$) returns to scale both lead to the same conclusions concerning the effects of changes in the TAC on equilibrium harvest. However, they have to be analyzed in two distinct sub-cases, which depend on the shape of the fish's global supply curve[10].

Proposition 1 *If* $\alpha < [\varepsilon/(\varepsilon-1)](1+1/\sigma)$*, the fish's supply curve is either increasing or decreasing in the global harvest-price locus.*

Proof. Eq. (13) immediately indicates that $\partial H^s/\partial P > (<)\ 0$ if $\Phi > (<)\ 0 \Leftrightarrow \alpha < (>)\ 1+\frac{1}{\sigma}$. Since $1+\frac{1}{\sigma} < \frac{\varepsilon}{\varepsilon-1}\left(1+\frac{1}{\sigma}\right)$ is always verified with $\varepsilon > 1$, one can have either $\alpha < 1+\frac{1}{\sigma} < \frac{\varepsilon}{\varepsilon-1}\left(1+\frac{1}{\sigma}\right)$ or $1+\frac{1}{\sigma} < \alpha < \frac{\varepsilon}{\varepsilon-1}\left(1+\frac{1}{\sigma}\right)$. ■

Corollary 2 *The equilibrium level of global harvest is an increasing function of the TAC.*

Proof. From Eq. (14), we indeed have $\partial H^*/\partial\overline{Q} > 0$ if $\Omega > 0 \Leftrightarrow \alpha < \frac{\varepsilon}{\varepsilon-1}\left(1+\frac{1}{\sigma}\right)$. ■

The rationale for the result entailed in Proposition 2 is the following. A reduction in the TAC, other things equal, leads to a rise in the ITQ price

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[10] An interesting theoretical situation could be obtained, caracterized by zero or multiple equilibria, if the global harvest supply curve were decreasing and concave in the global harvest-price locus. This would open up the possibility of multiple intersections with the decreasing and convex global demand curve. However, according to Eq. (13), these two properties respectively imply the following conditions: $\alpha > 1+1/\sigma$ and $\alpha < (1+\sigma)/2\sigma$, that cannot be simultaneously verified since $\sigma > 0$.

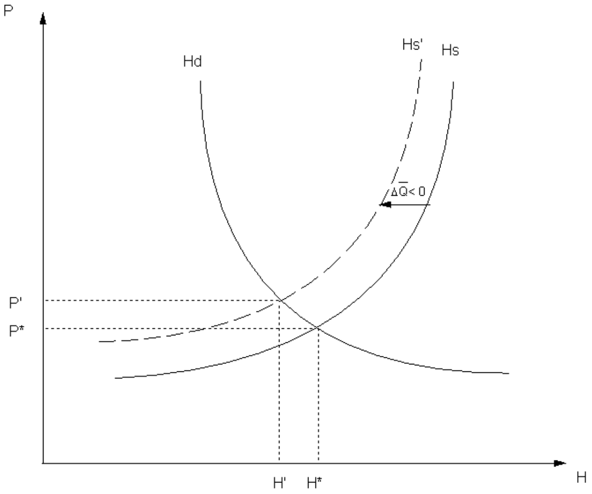

Figure 1: Impact of a reduction in the TAC on the equilibrium level of global harvest if $\alpha < 1 + 1/\sigma < (1 + 1/\sigma)\,[\varepsilon/\,(\varepsilon - 1)]$.

and thus in the costs born by firms. In all cases, this induces the latter to increase their price and to reduce their output (harvest) level. However, under "sufficient" returns to scale, the fall in the firms' marginal cost induced by an increase in their supply is stronger than the rise in the ITQ costs induced by the reduction in the TAC. This implies that in that second case, firms reduce their price while rising their harvest level. The two situations described in Proposition 1 and Corollary 2 are depicted in Fig. 1 and 2.

4.1.2 "Significant" economies of scale

This section highlights the importance of the degree of returns to scale that fisheries exhibit for the determination of global harvest and the efficiency of the ITQ management system. The following proposition deals with the implications of the existence of some "sufficient" amount of increasing returns to scale within the fishery:

Proposition 3 *If* $\alpha > [\varepsilon/\,(\varepsilon - 1)]\,(1 + 1/\sigma)$*, the fish's global supply curve is decreasing in the global harvest-price locus.*

Proof. Eq. (13) indicates that $\partial H^s/\partial P < 0$ if $\Omega < 0 \Leftrightarrow \alpha > 1 + \frac{1}{\sigma}$, which is verified if $\alpha > \frac{\varepsilon}{\varepsilon-1}\left(1 + \frac{1}{\sigma}\right)$ since, with $\varepsilon > 1$, $\frac{\varepsilon}{\varepsilon-1}\left(1 + \frac{1}{\sigma}\right) > 1 + \frac{1}{\sigma}$. ■

Corollary 4 *The equilibrium level of global harvest is a decreasing function of the TAC.*

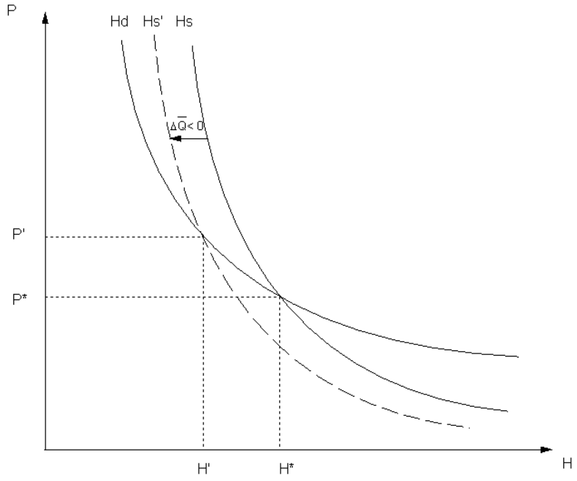

Figure 2: Impact of a reduction in the TAC on the equilibrium level of global harvest if $1 + 1/\sigma < \alpha < (1 + 1/\sigma)\left[\varepsilon / (\varepsilon - 1)\right]$.

Proof. From Eq. (14), we have $\partial H^{*}/\partial \overline{Q} < 0$ if $\Omega < 0 \Leftrightarrow \alpha > \frac{\varepsilon}{\varepsilon - 1}\left(1 + \frac{1}{\sigma}\right)$. ■

Proposition 3 notably shows that in the presence of sufficient increasing returns to scale within the fishery, a reduction in the TAC leads to a rise in the equilibrium level of global harvest. Indeed, returns to scale are in this case sufficiently increasing to induce, through a rise in the harvest level, a sufficient reduction in costs and price. This makes supply compatible with demand for a higher equilibrium harvest level and a lower equilibrium price level. This case is depicted in Fig. 3. Moreover, the proof of Corollary 4 indicates that such a situation is more likely to occur, the higher the price elasticity of demand (the higher ε, since $\lim_{\varepsilon \to +\infty} \left[\varepsilon / (\varepsilon - 1)\right] = 1$) and/or the more sensitive the amount of bycatch with respect to the material used by fishers (the higher σ).

4.1.3 Discussion

The central result of our paper is that the effects of changes in the TAC on global harvest crucially depend on the degree of returns to scale within fisheries. In particular, in the short run, where the capital stock remains fixed and where effort can be considered as the only variable input, a reduction in the TAC may increase global harvest if returns to effort are sufficiently strong. Whereas the impact of economies of scale on the evolution of biomasses has

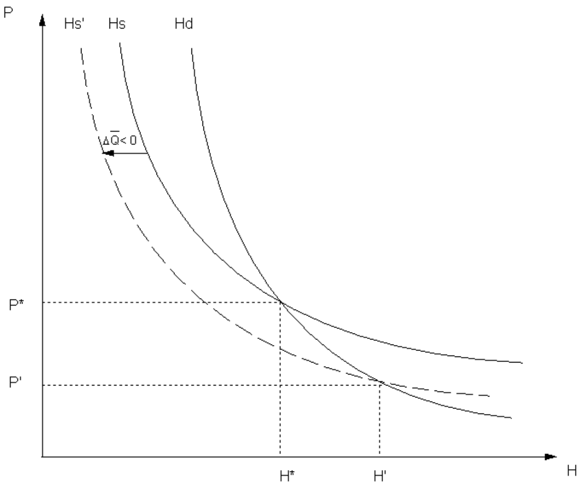

Figure 3: Impact of a reduction in the TAC on the equilibrium level of global harvest if $\alpha > (1 + 1/\sigma)\,[\varepsilon/\,(\varepsilon - 1)]$.

been widely analyzed, their effects on the economic working of fisheries and on the efficiency of ITQ systems have been much less studied. The theoretical results of the previous section seem to present a particular interest since fisheries concentrate activities that often exhibit substantial economies of scale. The existence of increasing returns in harvest may indeed come from the use of very effective means of capturing as in some North Atlantic fisheries, where schooling species "*behavior has permitted the development of very effective means of harvesting, in particular the purse seine. This means that with modern fish-finding equipment harvesting can be viable even at low stock levels*" (Bjorndal, 1989). Whereas some studies highlight the existence of decreasing or constant returns-to-effort (Opsomer and Conrad, 1994; Conrad, 1999), empirical evidence, based on the use of the standard Schaefer harvest (production) function, also often reveals the existence of increasing returns to scale at the whole fishery level, especially as far as big fisheries are concerned (Bjørndal, 1987; Bjørndal and Conrad, 1987; Eide *et al.*, 2003; Nøstbakken and Bjørndal, 2003; Bjørndal and Lindroos, 2004). Furthermore, scale economies in fisheries can often even be realized on the basis of the use of a sole variable input. The main question then deals with the scope of returns to that input, *i.e.* most often, to the extent of returns to effort given by the value of the harvest (output) effort elacticity. As in the case of returns-to-scale, this value remains a subject of debate and may vary accross fisheries. Empirical results obtained by Bjorndal (1989) indeed suggest a rising marginal product to effort, attributed to the existence of some virtuous interactions between pre-, post and main season fisheries. According to Bjorndal (1989), the existence of increasing returns comes from the organization of the fishing season itself: "*The herring are not randomly distributed in the ocean. At the beginning of the fishing season, time will be spent searching for herring. Once a catch has been made and delivered, the boat may return to the location of the first catch in the hope that the herring are still there. This learning effect may give rise to increasing returns, in particular in the pre-season*". Squires (1987), in an empirical analysis of New England multispecies fisheries, finds increasing product-specific returns for one of the species under investigation. Bjorndal *et al.* (1993a), in demonstrating that a generalized Cobb-Douglas production function may be more appropriate than the standard Shaefer one to describe harvesting in some fisheries, also show that the effort output elasticity may be signicantly different from one. They notably find increasing returns to effort for two distinct input variables (the number of boats and the number of days at sea).

4.2 The fish market structure

Another interesting result deals with the effects of changes in the degree of competition within the fishery on the efficiency of the ITQ policy. Eq. (14) also enables to formulate the following proposition concerning this point:

Proposition 5 *The impact of a change in the TAC on the equilibrium level of global harvest is amplified by an increase in the number of fishing firms or by a reduction in the conjectural parameter.*

Proof. Eq. (14) implies: $\frac{\partial}{\partial n}\left(\left|\frac{\partial H^*}{\partial \bar{Q}}\right|\right) > 0$ and $\frac{\partial}{\partial \phi}\left(\left|\frac{\partial H^*}{\partial \bar{Q}}\right|\right) < 0$. ■

As already seen, a change in the TAC leads, other things equal, to a change in the ITQs' price and, in turn, in the firms' costs and prices. But a simultaneous rise in the number of firms (or a simultaneous reduction in their conjectural parameter) makes competition become fiercer within the fish market, preventing firms from changing their price as strongly as in a less competitive environment. Firms hence will rather respond to a change in the TAC by modifying their supply, which reveals to be the variable that mainly absorbs the environmental policy shock. More broadly, Proposition 5 suggests that the effects of changes in the TAC on global harvest are magnified in more competitive fisheries.

5 Conclusion

This paper studies the theoretical implications of the implementation of an ITQ system for the management of bycatch. Our results help determining the conditions under which such a tool may be harmful for the economic activity of fisheries. We show that even the existence of a slight amount of increasing returns to scale within fisheries opens up the possibility of a decreasing relation between the equilibrium level of global harvest and the TAC set by regulating agencies. Such a link seems more likely to appear within fisheries where returns to scale are even weakly increasing, *i.e.* where the demand for fish is very elastic, or/and the amounts of bycatch are very sensitive to the material used by fishers. Our results put therefore into perspective the common idea according to which "*regulations have a cost in terms of efficiency because they prevent economies of scale in harvesting from being fully exploited*" (Bjorndal and Gordon, 1993). On the contrary in our framework, a reduction in the TAC leads to a rise in global harvest if returns to scale are sufficiently strong. This suggests that the efficiency of the environmental policy may depend on the scope of pre-existing economies of scale. Besides, the impact of a reduction in the TAC on global harvest seems to be stronger the fiercer the competition within fisheries, *i.e.* the higher the number of firms, or/and the more competitively the latter behave with respect to each other. This suggests that the fish market structure also appears to be an important element to be taken into account when designing fisheries management systems.

Lastly, one should of course be aware of the limits of our theoretical approach, which voluntarily neglects some important features of fisheries themselves. Firstly, one may question whether the hypothesis of increasing returns to effort is not too strong, especially for species that are not schooling ones and whose stock output elasticity is different from zero. As empirically put forth by Bjorndal (1989), "*One may question whether the results could be caused by externalities in production due to the exclusion of stock size as a variable in the production function. In a "pure" schooling fishery, stock size will not enter the production function. However, if the stock output elasticity is positive and stock size is changing over the year, there is an omitted variable problem which will cause a positive bias in the estimated effort output elasticity.*". More broadly, the link between economic and biological phenomena has been voluntarily ignored here, in order to focus the analysis on market considerations *per se.* About the latter, a better understanding of the working of fisheries would probably require a deeper analysis of the demand side of the fish market. All the preceeding questions are beyond the scope of this paper but may constitute interesting avenues for future research since, as put forth by Hall *et al.* (2000), “it is clear that by-catch management will be an integral part of most future ecosystem management schemes”.

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