Illegal Landings: An Aggregate Catch Self-Reporting Mechanism

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To solve the problem of illegal landings this article proposes a new tax mechanism based on the regulator’s own aggregate catch estimates and ex ante self-reports of planned catch by fishermen. We show that the mechanism avoids illegal landings while ensuring (nearly) optimal exploitation and generating (nearly) correct entry and exit incentives. Finally we simulate the mechanism for the Danish cod fishery in Kattegat to obtain a rough indicator of the size of the tax. It turns out that the average tax payment as a percentage of profit is surprisingly low.

Key words: entry and exit incentives, fisheries, illegal landings, optimal exploitation, self-reports, tax mechanism.

Fishing is a classic example of an open-access renewable resource problem requiring regulation if optimal exploitation is to be ensured. The problem arises because the individual fisherman disregards the effect of his catch on the costs of other fishermen through the resource constraint when he determines his catch level, and so regulation is necessary to internalize this external cost. In fact, fishing industries are regulated throughout the world with some form of individual quota system forming the core of many of the regulatory schemes applied today (see Wilen [2000] for a good survey). Much of the research on fisheries regulation has focused on introducing tradability in order to rectify the well-known efficiency problems resulting from nontradable quotas (see Clark [1980] for an original contribution). However, a subtle problem with individual quota systems (whether tradable or not) is the inherent risk of generating incentives for illegal landings and discards in connection with both target species and by-catches.1

Illegal landings can be defined as harvested fish that are landed and sold without proper notification of the fishing authorities (the regulator). Should the probability of detection or the expected punishment not be sufficiently large, fishermen may have an incentive to illegally land and sell fish in excess of the allotted quota. If different qualities of fish are covered by a single quota, the fishermen may also be induced to discard low-value qualities of a species so as to maximize the gross returns per quota ton (high grading). While discarding undoubtedly represents a serious problem for many quota regulation systems used today, a number of research papers have pointed out ways of refining tradable individual quota systems so as to reduce the incentives to high grade (e.g., Anderson [1986] suggests that quotas be differentiated according to quality and Turner [1996] proposes the use of value-based individual quotas). Furthermore, tradable individual quotas for both by-catches and target species can reduce incentives to discard by-catches (see Boyce [1996]). On the other hand, incentives to land illegally are an inherent characteristic of quota regulation. Refinements of individual quotas cannot eliminate incentives to land fish illegally, and such incentives must be checked by a properly designed control and enforcement system.

A number of studies estimating the magnitude of illegal landings suggest that such landings are a substantial problem for many quota-regulated fisheries today (studies covering a variety of species, countries, and regulatory specifications typically estimate illegal landings to be within the range of 10%–30% of legal catch weight: see Banks et al. (1997) for...
an overview). In principle, it should be possible to reduce illegal landings within the individual quota systems used today if regulators were to impose larger punishment or devote more resources to fisheries control. However, this does not seem to happen in practice. One reason may be that in many cases, substantially higher fines or punishment would be in conflict with general legal principles and practices dictating that punishment must be perceived as “reasonable” in relation to the crime, that is, the economic consequences of illegal landings. Increasing fishery control resources may also reduce the problem of illegal landings, but not necessarily in an efficient manner. If substantial increases in control resources are required, then restructuring the regulatory system to one less prone to illegal landings may be more efficient. It thus seems as though the development of alternative regulatory systems less prone to noncompliance could be a useful research endeavor given the substantial and inherent problems with illegal landings within many of the individual quota systems employed in contemporary fisheries regulation.

Although the problem of illegal landings has been recognized by a number of researchers (see, e.g., Sutinen and Andersen [1985], Copes [1986], Svelle et al. [1997]), the analytical framework of asymmetric information has not been applied to the problem of fisheries regulation until recently with only Jensen and Vestergaard (2002) having formally adopted this approach. In this article, the unobservability of individual catches is taken as a premise, and the authors propose using total fish stock as the tax base for a mechanism similar to the ambient tax suggested by Segerson (1988) for nonpoint emissions, where only aggregate emissions can be observed. As is the case with individually transferable quotas (ITQs), the mechanism in Jensen and Vestergaard (2002) requires that the regulator (a) knows the biological response function, (b) is able to measure the stock of fish, and (c) observes which vessels participate in resource exploitation, for example, through aerial and satellite monitoring of the regulated area. The advantage of the mechanism in Jensen and Vestergaard (2002) over ITQs is that effective control of landings of individual vessels is not necessary, since landings are not part of the tax base. However, the mechanism also has three potentially important disadvantages when compared to ITQs. First, in order to ensure optimal catches under the Jensen and Vestergaard scheme, the regulator must be familiar with the cost function of each individual fishing vessel, which is not necessary under ITQ regulation. Acquiring knowledge of the aggregate or mean cost function for a fishing industry is not a trivial task, but good estimates can often be produced using available research results, cost studies, and observable data such as tonnage (see Arnason et al. [2000] for an example in a Danish context). However, the task of acquiring knowledge of the individual cost function of each vessel in the industry would be substantially more demanding—if at all possible. Second, the Jensen and Vestergaard mechanism uses fish stocks as the tax base, and so in contrast to ITQs its performance depends critically on fishermen being able to correctly estimate how their own catch affects fish stocks through the biological response function. If, for example, fishermen completely disregard the influence their own catch has on total fish stocks, the mechanism in Jensen and Vestergaard (2002) would be perceived as a lump-sum tax, thereby having no effect on catches at all. In the nonpoint emission context, the potentially devastating effect of divergent regulator and polluter priors on ambient tax performance has been pointed out by Horan, Shortle, and Abler (1998), and essentially the same dependency exists for the mechanism in Jensen and Vestergaard (2002). Third, because measurement of stock size is notoriously imprecise, the use of this tax base in the mechanism in Jensen and Vestergaard (2002) may impose greater risk on fishermen than a corresponding ITQ scheme.

In this article, we propose a tax mechanism (inspired by Hansen and Romstad [2001]) which in its basic form consists of a tax equal to total industry cost (which is a function of total catch) less a lump-sum transfer. Rather than basing the tax on observed fish stocks (thereby leaving the problem of estimating the relationship between stocks and catch to fishermen), we propose that the regulator estimates the aggregate catch of the fishing industry and bases the tax on this measure instead. Each fisherman thus faces a marginal tax equal to the marginal costs incurred by the entire fishing industry when the aggregate catch is increased. Even if fishermen disregard the influence that their own catch has on total fish stocks, the tax generates correct marginal incentives and the distortion generated when fishermen have other estimates of the biological response function is “small” (the dependency of fishermen’s perceptions is bounded and the generated efficiency loss falls as the
number of regulated fishermen increases going to zero in the limit). Furthermore, the proposed tax does not require the regulator to have knowledge of individual vessel cost functions. However, the tax we propose still has one main drawback vis-à-vis ITQs, that is, that extra risk is imposed on fishermen.

The advantage of the proposed tax is (like the Jensen and Vestergaard scheme) that it makes it possible to avoid the costly control of landings required when regulation is based on individual quotas. Similar to an ITQ system, the proposed tax scheme induces (nearly) optimal individual catches and in addition generates (nearly) optimal participation, which is not ensured under quota regulation nor under the Jensen and Vestergaard scheme. In some regulatory settings, the economic barriers to entry are so substantial that the entry–exit problem may be ignored, at least in the short run. This is not the case in the fishing industry where the purely economic barriers to entry often are small even in the very short run, that is, in some cases equal to the cost of sailing from the current location to the regulated fishing zone. Nearly correct entry–exit incentives are ensured in our scheme by basing the lump-sum rebate part of the tax on ex ante self-reports of planned catch by fishermen. Because the rebate applied to any given fisherman only depends on the self-reporting of other fishermen, no incentives for misreporting are generated. Thus, this part of the tax reduces a potentially serious entry–exit inefficiency that plagues all previously proposed regulatory schemes in the fisheries economics literature including ITQ regulation. In addition, utilization of ex ante self-reporting is a novelty of the proposed scheme.\footnote{Under many of the fisheries regulation systems applied today, fishermen are asked to engage in ex post self-reporting by filling out logbooks. However, the self-reporting suggested here differs in two important respects. First, we propose ex ante elicitation of planned catch not ex post self-reporting of realized catch. Second, self-reporting is typically used to control the fisherman, thereby generating an incentive to misreport. We propose that the self-reporting from a given fisherman is merely used to control other fishermen, thus eliminating the incentive to misreport.}

In the following the tax scheme we propose is presented and analyzed in a single species, single quality, nonstochastic setting for reasons of parsimony. However, the suggested management system also eliminates incentives to discard (e.g., in connection with high grading) and incentives to illegally land and discard by-catch when the mechanism is adapted to the multispecies setting. The intuition for this is given where relevant in the following sections. The proposed scheme (with appropriate adaptations) also works in a stochastic environment, which we will also note where relevant in the following sections (see Hansen et al. [2003]).

Like a quota system the tax-based instrument suggested in this article is designed to implement an exogenous target level for total catch. Here we follow the tradition within fisheries economics of setting this target level at the economically optimal aggregated catch. However, this is not critical for our result. The tax mechanism proposed here can implement any arbitrary target level efficiently without the need of an expensive control and enforcement system to check for illegal landings. The result presented here should therefore also be relevant for fisheries where regulators prefer to set the target level for total catch according to biological criteria (as seems to be the case in many regulated fisheries today).

A general criticism of ambient taxes is that they may result in large tax payments, because the tax base is aggregate pollution, catch, or fish stock. This criticism goes to both the inefficiencies caused by the incorrect entry and exit incentives that might be generated as well as to the political feasibility of schemes involving large tax payments. Because the mechanism proposed here results in approximately correct entry and exit incentives, this aspect of the criticism is taken account of. However, the resulting payments may still be sufficiently large as to be politically infeasible. We therefore evaluate the size of the tax payment that would result if the proposed mechanism was applied to the Danish cod fishery in the Kattegat. The simulation results indicate that the tax payment would correspond to at most a little over 1% of gross profit (before capital depreciation).

In the next two sections we present our model and analyze the proposed tax scheme. Then we present simulation results for the Danish Kattegat cod fishery and the final section summarizes our conclusions.

The Model

For reasons of parsimony we confine our analysis to comparing between nonstochastic steady states, but the model and analysis generalize to a stochastic setting (see Hansen et al. [2003]).

In keeping with traditional fisheries economics, let $x$ be the stock size, $H$ the aggregated harvest, and $\dot{x}$ the stock change per time...
period. The change in stock size per time period is assumed to depend on stock size and harvest, that is, \( \dot{x} = F(x) - H \), where \( F(x) \) is the natural growth. In equilibrium steady state
\[
\dot{x} = 0, \quad \text{and } H \text{ must satisfy}
\]
\[
(1) \quad H = F(x)
\]
where \( x \) is stock size in the steady state. Equation (1) is known as the resource restriction. It is assumed that \( F'(x) > 0 \) for \( x < x_{\text{msy}} \) and \( F'(x) < 0 \) for \( x > x_{\text{msy}} \), where \( x_{\text{msy}} \) is the stock size corresponding to the maximal sustainable yield. Furthermore, it is assumed that \( F''(x) < 0 \). This assumption holds for the most commonly used growth functions; see for example Conrad and Clark (1991).

It is initially assumed that the fishing industry consists of \( n \) fishing vessels. The catch of fisherman \( i \), \( h_i \), is assumed to depend on the fish stock, \( x \), and the costs invested by the fisherman, \( c_i \). Thus, costs may be expressed as
\[
(2) \quad c_i = c_i(h_i, x)
\]
where we assume that \( dc_i/dx < 0 \) and that \( dc_i/dh_i > 0 \). The cost functions, \( c_i(\cdot) \), vary between fishermen, reflecting variations in assets and skills. We assumed that each fisherman knows his own cost function, but that individual fisherman’ cost functions are unknown to the regulator (relaxing the full information assumption made by Jensen and Vestergaard [2002]). Note also that \( H = \sum_i h_i \) is observed by the regulator, but that the individual \( h_i \) are not observed by the regulator.

The profit for fisherman \( i \) is
\[
(3) \quad \pi_i = ph_i - c_i(h_i, x)
\]
where \( p \) is the output price.

The optimal resource exploitation problem can now be specified assuming that steady-state resource rent of the industry is to be maximized under the resource restriction
\[
(4) \quad \text{Max} \sum_{i=1}^n \pi_i = \sum_{i=1}^n (ph_i - c_i(h_i, x))
\]
\[\text{s.t.} \]
\[
(5) \quad F(x) - H = 0
\]
where \( H = \sum_i h_i \).

This problem may be solved with a standard Lagrange method. The first-order condition of the Lagrange function with respect to \( h_i \) is 
\[
p - \frac{\partial c_i}{\partial h_i} - \lambda = 0, \quad \text{where } \lambda \text{ is the user cost of the fish stock (see Anderson [1986]). By taking the first-order condition with respect to } x \text{ together with the first-order condition for } h_i,
\]
it is easy to show that \( F'(x) < 0 \) in optimum. This allows a slightly different formulation of the problem, because the inverse function, \( F^{-1}(\cdot) \) is well defined on the subset of \( x \), where \( F'(x) < 0 \). Restricting to this subset \( (x > x_{\text{msy}}) \), equation (5) can be reformulated to yield
\[
(6) \quad x = F^{-1}(H) = M(H).
\]

Equation (6) is an expression of how the aggregated catch is related to the steady-state stock. From (6) a biological response function, \( \partial M/\partial h_i \), can be constructed, and because \( F'(x) < 0 \) for the subset of \( x \) considered, it follows that \( \partial M/\partial h_i < 0 \). It is assumed that \( H \) can be measured by measuring \( x \) and \( F(x) \), and because \( x \) and \( F(x) \) is nonstochastic, \( H \) is also nonstochastic.

By substituting (6) into (4), the following maximization problem for the regulator is obtained
\[
(7) \quad \text{Max} \sum_{i=1}^n (ph_i - c_i(h_i, M(H))).
\]
The first-order condition for \( h_i \) is
\[
(8) \quad p - \frac{\partial c_i}{\partial h_i} - \sum_{j=1}^n \frac{\partial c_j}{\partial M} \frac{\partial M}{\partial h_i} = 0 \quad \text{for } i = 1, \ldots, n
\]
Noting that \( \partial H/\partial h_i = 1 \), equation (8) can be rewritten as
\[
(9) \quad p - \frac{\partial c_i}{\partial h_i} - \frac{\partial C}{\partial M} \frac{\partial M}{\partial H} = 0 \quad \text{for } i = 1, \ldots, n
\]
where \( C(H, M(H)) \) is aggregate cost as a function of aggregate catch, \( H \). Let \( h_i^* \) denote the members of the solution vector for (7) given by (9) and define the aggregate optimal catch as \( H^* = \sum_{i=1}^n h_i^* \). In equation (9) the element \( -\partial C/\partial M \partial M/\partial H \) is the user cost of the fish stock that captures the marginal increase in fishing costs caused by increased catch through the resource constraint. This is (approximately) the external effect that fishermen do not take into account and which fishing regulations must compensate for.

Assuming that a regulatory tax \( (T_i) \) is imposed, the problem faced by fisherman \( i \) in the steady-state equilibrium for \( x \) is to maximize profit (defined in equation (3)) net of tax payments, that is,
\[
(10) \quad \text{Max} (ph_i - c_i(h_i, M(H)) - T_i).
\]
This maximization problem corresponds to the formulation in Arnason (1990). The first-order profit maximization condition of the fishermen then becomes

\[
p - \frac{\partial c_i}{\partial h_i} - \frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H} - \frac{\partial T_i}{\partial h_i} = 0. \tag{11}
\]

The free-riding problem of common resource extraction (see, for example, Clark [1990]) occurs because unregulated fishermen (where \(\frac{\partial T_i}{\partial h_i} = 0\)) set their catch so as to maximize profits while disregarding the cost effect this has on other fishermen through the resource restriction, that is when comparing with the optimal first-order condition, (9), fisherman \(i\) only takes into account the resource constraint effect on his own costs, \(-\frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H}\), whereas optimality would require that he takes account of the resource constraint effect on the costs of the entire industry, \(-\frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H}\).

Though (11) is the objective first-order condition for profit maximization, the extent to which fishermen realize or take account of the fact that their own catch affects their own costs through the resource constraint is unclear. Practical experience presumably allows fishermen to ascertain the relationship between invested cost and catch, that is, \(-\frac{\partial c_i}{\partial h_i}\), whereas the resource constraint effect, \(-\frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H}\), is indirect and small (see Clark [1990]). In order to capture variations in the fisherman’s perception of the resource constraint effect in a simple way, a parameter, \(\alpha_i\), is introduced as in Jensen and Vestergaard (2002), and it is assumed that the fisherman selects catch according to the following first-order condition:

\[
p - \frac{\partial c_i}{\partial h_i} - \alpha_i \frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H} - \frac{\partial T_i}{\partial h_i} = 0, \quad 0 \leq \alpha_i \leq 1 \tag{12}
\]

where \(\alpha_i\) may attain values between 0 and 1. If \(\alpha_i = 1\), the fisherman uses a correct estimate of the biological response effect when maximizing profits. If \(\alpha_i = 0\), the fisherman’s perception is that catches do not influence fish stocks. Irrespective of the value of \(\alpha_i\), the resource will be over-utilized, because fishermen do not take account of the increased fishing cost on other fishermen resulting from reducing the equilibrium fish stock. The regulator’s problem is to set a tax capable of internalizing this effect. In the following section, a tax is proposed as a solution to this problem. It is then shown that this tax provides almost correct marginal catch incentives and almost correct entry and exit incentives.

### A Tax Mechanism Based on Aggregate Catch

#### The Information Assumptions

First, consider the information that the regulator can base a tax on. By assumption, the individual cost functions, \(c_i(\cdot)\), are not known to the regulator, and the individual catches, \(h_i\), cannot be observed by the regulator. However, it is assumed that the regulator, in addition to knowing the biological response function, \(M(\cdot)\), also knows the aggregate cost function, \(C(\cdot)\). Furthermore, the regulator estimates aggregate catch by measuring \(x\) and using his knowledge of \(F(x)\). Thus, in the proposed system, the regulator merely measures the aggregate catch—he does not attempt to measure the catch of each individual fisherman by controlling landings as in an ITQ system. Because no attempt to record individual landings is made (and because all landings affect stocks), the concept of illegal landings essentially disappears.3

Given knowledge of \(M(\cdot)\) and \(C(\cdot)\), the regulator can solve the following problem:

\[
\text{Max}_{H} \left[ ph - C(H, M(H)) \right]. \tag{13}
\]

Equation (13) implies that the optimal aggregate steady-state catch, \(H^*\), is also known by the regulator.

Now consider the modeled behavior of fishermen. It is assumed that fishermen are able to ascertain the direct relationship between invested costs and catch and so maximize profits in this dimension, which seems realistic. Furthermore, the model allows for imperfect perceptions of the resource constraint effect through the \(\alpha_i\)—parameters in the fisherman’s first-order condition, (12). Finally, it is also assumed that fishermen can explicitly formulate precise catch expectations for the coming period and that they can ascertain tax payments when given knowledge of tax payment function. Clark (1985) describes an empirical investigation of the ability of fishermen to form catch expectations for a search fishery and finds that fishermen may be able to formulate

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3 Because individual landings are not recorded, the scheme does not generate incentives to discard (at any rate mortality in connection with discards will affect stocks so this does not present itself as a way to reduce tax payment).
such expectations. Thus, this common assumption in fisheries economics also has empirical support.

**The Tax Scheme**

The regulator’s problem is to design a tax scheme based only on his knowledge of aggregate functions and measured aggregate catch. We propose that the regulator implements a tax scheme based on this and in addition elicited *ex ante* self-reports of each fisherman’s planned catch.

Initially, the tax scheme is made public and each participating fisherman is asked to reveal the catch he plans for the coming season. Let $s_i$ denote the *ex ante* self-report made by fisherman $i$. After the fishing season, each fisherman pays a tax $(T_i)$ in accordance with the revealed scheme. Timing of the various decisions made by fishermen and the regulator over the fishing season is shown in figure 1.

The announced formula for calculation of the tax (in monetary units) to be paid by fisherman $i$ after termination of the fishing season is

\[
T_i = C(H^*, M(H)) - C\left(H^*, M\left(\sum_{j \neq i} s_j\right)\right) + q\left(H - \sum_{i=1}^n s_i\right)^2.
\]

(14)

The first element (right-hand side of (14)) of the proposed tax, $C(H^*, M(H))$, is effectively an ambient tax on the aggregate steady-state catch, which in optimum is equal to total fleet costs. This tax element is a function of optimal aggregate catch calculated by the regulator, actual aggregate catch measured by the regulator, and is designed to ensure approximately correct marginal catch incentives for participating fishermen (e.g., like the ambient mechanism proposed by Jensen and Vestergaard [2002]). The second element, $-C(H^*, M(\sum_{j \neq i} s_j))$, is a refund based on optimal aggregate catch calculated by the regulator and the fishermen’s *ex ante* reports of planned catch. The refund is designed so that the total tax payments of fishermen provide approximately correct entry and exit incentives. Note that if *ex ante* self-reports are truthful, this refund is equal to total costs of all other fishermen’s catch in optimum. The last element, $-q(H - \sum_{i=1}^n s_i)^2$, is a penalty based on total catch measured by the regulator and the fishermen’s *ex ante* reports of planned catch, which is designed to induce truthful *ex ante* self-reporting. If truthful self-reporting is induced for all fishermen the last element of the tax equals zero.

**Nash Equilibrium under Tax Regulation**

After the tax formula is revealed (see figure 1) each fisherman is asked to self-report planned catch. At this point in time the fisherman must plan his catch and decide what to self-report, that is, fisherman $i$ must set $h_i$ and $s_i$ so as to maximize profit (the first square bracket in (15) minus tax payment (the second square bracket in (15)). Thus, fisherman $i$ solves the following problem:

\[
\begin{align*}
\text{Max}_{h_i, s_i} & \left[ ph_i - c_i(h_i, M(H)) \right] \\
& - \left[ C(H^*, M(H)) + C\left(H^*, M\left(\sum_{j \neq i} s_j\right)\right) + q\left(H - \sum_{i=1}^n s_i\right)^2 \right].
\end{align*}
\]

(15)
Assuming that the fishermen have Nash conjectures\(^4\) \(\left(\frac{\partial M}{\partial h_i} = 1\right)\), the first-order profit maximization conditions for fisherman \(i\) are

\[
\begin{align*}
2q \left( H - \sum_{j=1}^{n} s_j \right) &= 0 \\
\left[ p - \frac{\partial c_i}{\partial h_i} - \alpha_i \frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H} \right] + 2q \left( H - \sum_{j=1}^{n} s_j \right) &= 0
\end{align*}
\]

where (16) and the second square bracket in (17) derive from the tax formula and the first square bracket in (17) derives from normal profit maximization. Rearranging and inserting (16) into (17) gives

\[
\begin{align*}
p - \frac{\partial c_i}{\partial h_i} - \alpha_i \frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H} - \frac{\partial c}{\partial M} \frac{\partial M}{\partial H} &= 0 \\
s_i &= H - \sum_{j \neq i}^{n} s_j.
\end{align*}
\]

We see that all self-reports (the fisherman’s own as well as other fishermen’s) have been eliminated from equation (18) so that optimal catch can be found independently of self-reporting by solving (18) for \(h_i\). Note also that each fisherman has all the necessary information for solving this problem because he knows his own cost function and is informed of the tax formula. Next we see from (19) that the profit-maximizing self-report is the self-report that ensures that the sum of all fishermen’s self-reports equals planned aggregate catch. We thus have clear causal relationship between the fisherman’s two decision variables: first, the fisherman finds his optimal catch (from (18)) then makes a self-report of planned catch that ensures “aggregate truth telling.” However, when solving the self-report problem the fisherman lacks information about what other fishermen are self-reporting. He does not know whether other fishermen are over- or underreporting and so does not know how much he should over- or underreport so as to counteract this and ensure aggregate truthful revelation. On the other hand, he does know that all other fishermen have the same incentive to ensure truthful aggregate self-reporting and so would only have an incentive to over- or underreport as a reaction to conjectures that some other fisherman for some reason was over- or underreporting. If all fishermen behave rationally and all fishermen know that all fishermen are aware of this there is only one way to play this game and that is to make individually truthful self-reports. Without specific knowledge of other fishermen making self-reporting mistakes any other self-reporting behavior would be irrational, and so individual truthful self-reporting becomes part of a unique Nash equilibrium.\(^5\)

By comparing (18) where the fisherman finds profit-maximizing catch under the proposed tax scheme with (9), the optimal catch, we see that the tax results in correct marginal incentives if \(\alpha_i = 0\), but “over-corrects” if \(\alpha_i > 0\). The tax corrects for the external stock effect of fisherman \(i\)’s catch on other fishermen, \(\frac{\partial M}{\partial h_i}\), as it should, but also for the perceived part of the stock effect on fisherman \(i\) himself, \(\alpha_i \frac{\partial c_i}{\partial M} \frac{\partial M}{\partial H}\), which is an internal effect that fisherman \(i\) already takes into account. However, as the number of participating fishermen increases, \(\sum_{j \neq i} \frac{\partial c_j}{\partial M} \frac{\partial M}{\partial H}/\sum_{j} \frac{\partial c_j}{\partial M} \frac{\partial M}{\partial H}\) approaches one so that irrespective of the value of \(\alpha_i\), the incentive error falls and goes to zero in the limit. Thus, if the number of fishermen is sufficiently large, the tax generates catch incentives that are approximately equal to the optimal incentives in (9), because the internal stock effect (even if \(\alpha_i = 1\)) as a proportion of the total industry stock becomes small (close to zero).

This result is only driven by the first element of the mechanism in (14), \(C(H^*, M(H))\). The remaining tax elements are independent of \(h_i\) when ex ante self-reporting is truthful, and the tax elements are then perceived as lump-sum taxes and rebate elements that the fisherman

\[
5\text{ This is a Nash equilibrium in pure strategies because for all fishermen we have that altering self-reports or catch cannot increase profit given the behavior of all other fishermen. Assuming rational behavior by all fishermen and ignorance of other fishermen’s self-reports this is a unique Nash equilibrium. However, if we allow fishermen to make self-report mistakes and other (rational) fishermen to somehow observe this, other equilibria become possible (those where other fishermen in various combinations ensure aggregate truth telling by compensating for the mistakes made in self-reports filed by fishermen who make self-report errors).}
\]

\[
4\text{ Since catch } h_i\text{ is not observed by other fishermen Nash-Cournot conjectures can be rationalized.}
\]
can only influence through his participation decision.

**Optimal Entry and Exit Incentives**

In the Appendix, it is shown formally that the suggested tax, (14), ensures approximately correct entry and exit incentives. Here we provide an intuitive explanation as to why this is so.

The optimal group of participating fishermen is the group that maximizes industry profits. Following Horan, Shortle, and Abler (1998), the participation condition for fisherman $i$ in optimum is that the sum of profit increases experienced by the remaining fishermen (after having adjusted their catch levels to new marginal optimality conditions) if fisherman $i$ were to exit, is smaller than the profit loss experienced by fisherman $i$. Let $A^i$ denote this sum of profit increases experienced by the remaining fishermen if fisherman $i$ were to exit.

The basic idea here is to design the second lump-sum refund element of the tax so that total tax payment for fisherman $i$ equals $A^i$. If this were possible, the optimal industry structure would be induced, because the marginal nonparticipating fisherman would face a tax greater than the total profit he could earn by entering the fishery, while the marginal participating fisherman would continue to make a net profit after tax and thus continue to participate.

In fact, the total tax paid under (14), $C(H^*, M(H)) - C(H^*, M(\sum_{j \neq i} s_j))$, equals the costs saved by the remaining fishermen without adjusting their catch levels to new marginal optimality conditions if fisherman $i$ were to exit. This again equals the profit increase that would be experienced by other fishermen without adjusting catch levels. Though the generated entry and exit incentive is not optimal, it comes close in that the generated tax payment corresponds to a first-order approximation of the correct incentive, $A^i$. Furthermore, as the number of fishermen $n$ increases, the effect of the incentive error falls going to zero as $n$ goes to infinity (as is shown in the Appendix).

**Extensions**

It is straightforward to extend the model and proposed mechanism to a deterministic multispecies setting and to take account of known seasonal variation. The model and the mechanism also extend to a stochastic setting where stock size, aggregated catches, and individual catches are stochastic variables when the tax scheme is adapted appropriately (see Hansen et al. [2003]). This allows, for example, stochastic seasonal variation to be taken into account. Furthermore, it is straightforward to extend this model and tax scheme to a stochastic multispecies setting. Finally, dynamic model versions where adjustment toward steady state is modeled explicitly are obvious extensions.

Finally, in addition to externalities working through the fish stock, congestion externalities may also arise in some fisheries (when congestion in itself causes fishing costs to rise, see, e.g., Boyce [1992], Brown [1974], and Smith [1969]). This requires the introduction of another regulatory instrument aimed at correcting the congestion externality in addition to the tax suggested here (which is only designed for correcting the basic externality working through fish stocks).

**Simulation Results**

In this section we present an application of the proposed tax scheme simulated for the Danish cod fisheries in the Kattegat. The Danish cod fishery in the Kattegat currently grosses about 6,800 tons/559 million DKK sales value per year with some 250 fishing vessels participating during a typical year (see Anon [1997]). The average gross profit per vessel (sales value less variable costs) is about 97,000 DKK. The fishery is currently regulated through a system of nontradable quotas (see Arnason et al. [2000]). These regulations are enforced by the Danish Fisheries Inspection through random harbor controls and cross-checking of logbooks and sales notes at first-hand sales (see Banks et al. [1997]). Fishermen in violation are typically fined and profits from illegal landings are confiscated. For the Danish cod fishery in the North Sea (that is subject to the same regulation and enforcement system) Banks et al. (1997) estimate that illegal landings account for about 20% of total landings suggesting that there may be a comparable compliance problem for the Kattegat cod fishery.

Tax payment is simulated for the average vessel within each of the following groups of vessels (Netters under 20 Gross Tons (GT), Netters over 20 GT, Danish Seiners, Trawlers under 50 GT, Trawlers between 50 GT and 199 GT, and Trawlers over 200 GT). These groups span the most important differences in the vessel capacity and technology and the data period covers both good and bad years so that the simulations presumably capture much of...
the variation that might be expected in tax payments. Tax payment for each type of vessel is simulated under the assumption that the aggregate steady-state equilibrium, that is, that $H$ is equal to $H^*$. Focusing on tax payment after adjustment to the optimal steady state allows interpretation of the calculated tax payment as the long-run or permanent financial impact on the fishing industry.

In order to calculate the tax to be paid (given in equation (14)), it is necessary to obtain an expression for a cost and growth function. A logistic growth function is estimated with standard econometric methods based on a time series of catches and stock size for the period 1971–98 (see Hansen et al. [2003] for details)

$$F(x) = rx \left(1 - \frac{x}{K}\right)$$

where $r$ is the intrinsic growth rate and $K$ is the carrying capacity.

The cost function is calibrated using the following cost specification:

$$C(H, x) = \frac{cH^2}{x}$$

where $c$ is a variable cost parameter. Equation (21) is common in fisheries economics and the derivatives of (21) are reasonable; see for example Arnason et al. (2000).

In figure 2, the average tax payment in percentage of gross profit (before capital depreciation) is presented for each vessel group.

Figure 2 illustrates that the variation in the average tax payment is substantial. However, the percentage is very small in all cases at most 1.1% of gross profit. This result, covering variations in vessel type, good and bad fishing years, and variation in key parameters, appears robust.

Because the simulations are conducted for the long-run bioeconomic yield, the total tax payment will be equal to the resource rent. In other words, because the tax ensures an almost optimal amount of catch, and at the same time almost optimal entry and exit, imposing the tax in equilibrium exhausts the resource rent. The results therefore also indicate that the total resource rent earned by fishing cod in the Kattegat is small. Squires, Alauddin, and Kirkley (1994) estimate that the mean rent per vessel in the sable fishery for the long-line fleet in Washington, Oregon, and California is between $77 (DKK 462) and $58 (DKK 348) while Grafton (1995) estimates the mean rent in the British Columbia sable fishery to $189 (DKK 1134).

Thus, the estimated mean rent (the average tax payment) for the cod fishery in Kattegat is quite low compared to estimates for other fisheries in the literature. However, the rent’s share of gross profit in Squires, Alauddin, and Kirkley (1994) is at most 10%, while the share of the gross profit is 20% in Grafton (1995). In conclusion that the average tax payment generated by the proposed scheme constitutes a
small share of the profit may also hold for other fisheries.

Discussion and Conclusion

Traditional quota regulation requires the regulator to measure the landings of each individual fisherman making costly control measures to check illegal landings necessary. In this article, we have proposed a tax based on aggregate catch measured by stock changes. This makes it possible to avoid the costly control of landings (though this also in many cases would make it necessary to revise stock estimation procedures so that they become independent of landings data, i.e., relying exclusively on data from, e.g., survey trips). Like an ITQ system, the suggested tax scheme induces (nearly) optimal individual catches and in addition induces (nearly) optimal participation (which is not ensured under quota regulation). Finally, in contrast to the tax mechanism proposed by Jensen and Vestergaard (2002), our scheme does not require that the regulator knows the cost functions of individual fishermen, nor does it depend critically on fishermen’s perceptions of the biological response function.

There is one main drawback of the proposed tax vis-à-vis ITQs, which is that extra risk is imposed on fishermen. In addition, the very idea of utilizing taxes to regulate fisheries has been questioned by, for example, Clark (1990) pointing out that tax regulation may be considered unfair or politically unattractive. Because the generation of correct entry and exit incentives necessarily implies net taxation under our mechanism, the usual solution to this income distribution problem (recycling tax revenue back to the fishing industry in a lump-sum manner) cannot be applied here. Though our simulations of the proposed tax indicate that the income redistribution resulting from a shift to tax regulation would be small in the case of the Danish Kattegat cod fishery, this may not hold for other fisheries. So if regulators are apprehensive about imposing net taxation on fishermen they may be reluctant to apply the ideas suggested in this article. Addressing the problems of redistribution and extra risk imposed on fishermen implied by the proposed mechanism therefore seem relevant subjects of future research.

References


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Appendix: Entry and Exit Incentives

Let \( \theta \) denote the optimal set of participating fishermen. Furthermore, let \( h_{ij}^* \) denote the optimal expected catch level for fisherman \( i \) (given by first-order equation (13)) when all fishermen belonging to \( \theta \) participate at their optimal catch levels. Correspondingly, \( h_{ij}^{h(i)} \) denotes the optimal expected catch level for fisherman \( i \) when all fishermen belonging to \( \theta \{i\} \) participate at their optimal catch levels. Define the corresponding aggregate catches as \( H_{ij}^* = \sum_{j \in \theta} h_{ij}^* \) and \( H_{ij}^{h(i)} = \sum_{j \in \theta \{i\}} h_{ij}^{h(i)} \). Furthermore, define \( h_{ij}^{*0(i)} \) as the optimal expected catch level for fisherman \( i \) (given by first-order equation (13)) when the aggregate catch is \( H_{ij}^{0(i)} \), that is, the optimal expected catch if for some reason, for example the exclusion of other fishermen, the aggregate expected catch of the industry including fisherman \( i \) is at this level. This constructed optimal catch concept is used in the following as is the constructed aggregate catch concept defined as \( H_{ij}^{0(i)} = H_{ij}^{0(i)} + h_{ij}^{*0(i)} \).

Following Horan, Shortler, and Abler (1998), the following condition is sufficient for \( \theta \) to be the optimal set of producing firms:

\[
(A.1) \quad \sum_{j \in \theta} \pi_j \left( h_{ij}^* \right) \geq \sum_{j \in \theta \{i\}} \pi_j \left( h_{ij}^{h(i)} \right) \quad \text{for } i \in \theta
\]

and

\[
(A.2) \quad \pi_i \left( h_{ij}^* \right) - \left[ \sum_{j \in \theta \{i\}} \pi_j \left( h_{ij}^{h(i)} \right) - \sum_{j \in \theta \{i\}} \pi_j \left( h_{ij}^{*0(i)} \right) \right] \geq 0.
\]

From equation (A.1), it is straightforward to see that the following condition must hold for the marginal participating fisherman \( i \)

\[
(A.3) \quad \pi_i \left( h_{ij}^* \right) - C(H_{ij}^{0(i)}, M(H_{ij}^{0(i)})) + p \left( H_{ij}^{0(i)} - H_{ij}^{0(i)} \right) + C \left( H_{ij}^{0(i)}, M \left( H_{ij}^{0(i)} - h_{ij}^{*0(i)} \right) \right) - \left( \pi_i \left( h_{ij}^{*0(i)} \right) - \pi_i \left( h_{ij}^{*0(i)} \right) \right) \geq 0.
\]

Now consider the entry and exit incentives for fisherman \( i \) generated by the proposed tax mechanism in the truth-telling Nash equilibrium, given that all fishermen in \( \theta \) participate and the number of fishermen is large enough for marginal tax incentives to be considered optimal. Inserting truthful self-reporting, \( H = H_{ij}^* \) and \( h_i = h_{ij}^* \) into the net profit expression, the condition for participation in tax equilibrium becomes
\[
\pi^i(h_i^{*i}) - C(H_i^{*i}, M(H_i^{*i})) + p(H_i^{*i} - H_i^{*i}) + C(H_i^{*i}, M(H_i^{*i} - h_i^{*i})).
\]

(A.4)

Note that the elements \(+ p(H_i^{*i} - H_i^{*i}) = 0\) and \(- (\pi_i(h_i^{*i}) - \pi_i(h_i^{*i})) = 0\) are also added to facilitate comparison with the optimal entry and exit conditions (A.3). Note also that the only difference between (A.3) and (A.4) is that all elements in (A.3) that are evaluated at the after-exit optimum \((\ast \theta \{i\})\) values have been evaluated at the initial, before-exit optimum \((\ast \theta)\) values. Thus, the resulting tax payment is a first-order approximation of the correct tax payment, because account is not taken of the second-order adjustment to new marginal optimality conditions.

Now consider the optimal entry and exit incentive, (A.3), as the number of fishermen increases. As \(n\) increases \(\frac{H_i^{*i} - H_i^{*i}[i]}{H_i^{*i}}\) and \(\frac{h_i^{*i} - h_i^{*i}[i]}{h_i^{*i}}\) goes toward 0 and the shift in optimal catch induced by the exit of fisherman \(i\) can be considered marginal in the limit. For marginal changes from the optimal state, first-order conditions apply; in the limit \(n \to \infty\), it then follows that:

\[
\begin{align*}
\pi_i(h_i^{*i} - \pi_i(h_i^{*i})) = \\
pH_i^{*i} - C(H_i^{*i}, M(H_i^{*i} - h_i^{*i}))
\end{align*}
\]

(A.5)

Thus, in the limit (A.3) is equal to (A.4) so that as the number of fishermen increases, the entry and exit incentive error falls (going to zero in the limit).