Moral Hazard Problems in Fisheries Regulation: The Case of Illegal Landings[1]

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Abstract

This paper treats illegal landings as a moral hazard problem that arises, since individual catches are unobservable to society and hence private information. A tax/subsidy mechanism taking into account the asymmetric information problem is formulated as a solution to problems with illegal landings. The incentive scheme uses fish stock size as the tax variable, and can be seen as an alternative to a control policy. Rough estimates from a simulation study suggest that the incentive scheme is potentially useful. The incentive scheme also has potential application as an instrument to the solution of by-catch and discard problems.

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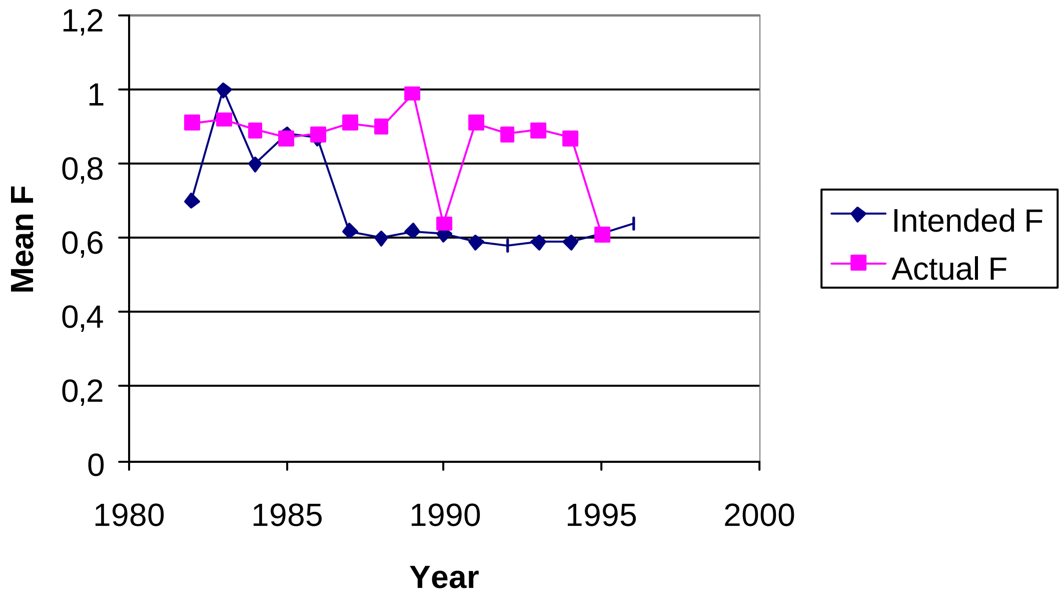
1. Introduction

Regulating industries by output control where output is costly to observe can run into problems with unreported outputs (for example pollution). In fisheries this problem arises as illegal landings, discard and by-catches, see Clark (1985) and Copes (1986). In figure 1 the magnitude of this problem is illustrated for cod in the North Sea.

Figure 1: Intended and actual fishing mortality for the North Sea cod



Source: Svelle *et al* (1997)

It is seen that the actual fishing mortality is generally much higher than the intended fishing mortality. This is partly due to misreported landings and discard. Indeed Svelle *et al* (1997) claim that for cod in the North Sea discards are 22% of the catch weight and 51% of the number of caught fish. Discard is also a major problem within the European Union (EU) (Commission (1992a)), and at a global level Alverson *et al* (1994) show that by-catches and discard pose problems. The main purpose of a quota system is to conserve the resource stock and unreported catches undermine this purpose. This leads to threaten stocks and low economic returns in the sector.

In the literature there is, however, some confusion with respect to the content of the concepts of illegal landings, by-catches and discard. Following Alverson *et al* (1994) illegal landings are defined as catches in excess of the quota sold through out illegal channels. Discard is the portion of the catch returned to the sea and by-catches are discard plus incidental catches, where incidental catch is retained catch of non-targeted species. High grading arises when the less profitable part of a catches is discarded.

In this paper attention is restricted to illegal landings even though the economic incentive scheme analysed here has potential application to the solution of problems associated with discard and by-catches. The problem of illegal landings is viewed as a problem that arises because individual catches cannot be observed. In effect this is a moral hazard problem, since an endogenous variable is unobservable, see for example Laffont and Tirole (1993). Based on the work of Holmstrom (1982) on moral hazard in teams and Segerson (1988) on non-point pollution, a stock tax/subsidy mechanism is presented, simulated and discussed. The proposed mechanism is similar to the mechanism proposed in Sergerson (1988). In both cases an individual pays on the basis of the full damage an activity courses in order to eliminate free-riding. However, there are four differences from Segerson (1988). Firstly, for example, Kolstad (2000) argue that the mechanism functions best in small groups. This point is easily seen from the analysis in this paper. Secondly, the mechanism is simulated, and the simulation results show that the variable tax is surprisingly low. Thirdly, the tax structure is different because of the resource stock restriction. It is shown that the tax must be based on the user cost of the resource stock. Fourthly, another information structure is assumed. Segerson (1988) assumes that one variable is unobservable to both actors. In this paper individual catches is unobservable to society and the stock size is unobservable to the fishermen. This difference is due to different policy problems analysed.

Some comments on the economic literature on discard and by-catches are useful. Copes (1986) discusses possible solutions to high grading problems. It might be possible to reduce discarding to a tolerable level by fine tuning regulations. Separate quotas might be given for different species or for different fish sizes that have different values per unit weight. Anderson (1994) analyses the economics of high grading in terms of the operating decisions of individual vessels. The study shows that it can be socially optimal to high grade with landing constraints that are costly to relax, and that individual transferable quotas (ITQs) can cause high grading when it is not socially optimal. Arnason (1994) develops a dynamic model that explicitly considers different grades of fishes to examine the catch discarding problem. The study shows that in a differentiated fishery discarding of catch may be socially optimal. Sampson (1994) develops a model for selection of fishing locations by a fisherman faced with two species whose densities vary with distance from the port. The study shows that trip quotas can be effective in protecting a species only when the two fish stocks are reasonably well separated. Boyce (1995) considers two fisheries – one for a target species and one for a by-catch species. The by-catch rate is positively related to the harvest rate of the target species. The study shows that a competitive ITQ system is capable of maximising social welfare, but that there must exist quota markets for both target and by-catch species. The approach taken in this paper is different from these approaches since it is argued that individual catches are unobservable due to illegal landings. Indeed, the existing literature fails to acknowledge that illegal landings and discard arise because catches are unobservable.

Some comments on the literature of illegal landings are also worth mentioning. Based on the economics of crime (Becker (1968) and Stigler (1971)), the literature studies fishery enforcement (Andersen and Sutinen (1983), Sutinen and Andersen (1985), Milliman (1986), Anderson and Lee (1986), Anderson (1987) and (1989), Neher (1990b), Sutinen (1993) and Charles (1993). Two fundamental results are established. Firstly, with costly enforcement it will not be optimal to ensure complete compliance. Secondly, in such situations it can be expected that illegal activity occurs on the basis of marginal returns to individual decisions. The approach taken makes it necessary to have a control policy, and the world wide policy response to the problems associated with illegal landings have been such a policy. In the EU, the control policy is judged to be ineffective, see for example Commission (1992b) and Jensen (2000). It is therefore important to search for alternatives to a control policy, and the mechanism proposed in this paper can be seen as an alternative.

In section 2, a theoretical analysis of the proposed mechanism is presented, while section 3 contains a simulation study of the incentive scheme. Problems associated with the mechanism are discussed in section 4, and section 5 concludes the paper.

2. Illegal landings and the incentive scheme

Imagine an industry consisting of n fishermen and let society impose a total quota on the industry. No matter which allocation scheme is chosen, there will be a compliance problem with a total quota system, see Copes (1986).

In the present paper, individual catches are assumed to be unobservable due to illegal landings, whereas total catches are assumed to be observable due to measurement of the fish stock. This setup is similar to individual pollution in the non-point pollution literature, see Hanley *et al* (1997) for an overview.[2] It is well known that there are random fluctuations and errors in measuring the stock size. However, two points are worth mentioning in this respect. Firstly, the problem is also considerable in the measurement of pollution in the non-point pollution literature. Secondly, observable catches are partly the basis for the stock calculations. Therefore, part of the measurement problem associated with stock size is due to unobservable catches. By using the stock tax proposed here, all catches are made observable, and therefore the stock estimate will become more precise. In other words the proposed mechanism can be used to reveal the private information about catches that the fishermen have.

2 Non-point pollution is defined as the case, where individual pollution cannot be measured.

Segerson (1988) proposes a tax/subsidy mechanism as a solution to non-point pollution problems. This mechanism is analysed here and the scheme is as follows:

$$T_i(x) = \begin{cases} t_i(x^* - x) & \text{for } x > x^* \\ k_i + t_i(x^* - x) & \text{for } x < x^* \end{cases} \qquad (1)$$

where:

x is the observable actual size of the fish stock.

x* is the optimal stock size.

T_i (x) is the tax function for fishermen i. Note that the fish stock is the basis for the tax, since individual catches cannot be observed.

t_i is the tax/subsidy rate, which can vary between fishermen.

k_i is a fixed penalty.

The proposed mechanism functions as follows. At the start of the year, society announces a tax/subsidy formula, and at the end of the year society may for example collect the tax. Two interpretations of the tax are possible. Firstly, society can announce x*. In this interpretation (1) becomes an alternative to a total quota policy. Secondly, on the basis of a growth function, the optimal aggregated catches, h*, can calculated and a total quota on h* can be announced in combination with (1). In other words, both h* and x* are announced. Now the stock tax is an alternative to a control policy. The second interpretation is chosen, since it is probably easier for the fishermen to understand a total quota, since catches, and not stock size, is their choice variable.

What is of interest is calculating t_i and k_i (section 2.3).[3] In order to calculate the variable tax rate and the fixed penalty, the optimal catches must be calculated (section 2.1). Further a model for fishermen behaviour is needed (section 2.2), since the first-order condition for a fisherman must be set equal to the condition for optimal catches in order to find t_i and k_i.

2.1. Optimal catches

For society, individual catch for fisherman i, h_i, is assumed to be a stochastic variable because of the compliance problem associated with the total quota. ε is a random variable associated with individual catches, but in the notation ε is submitted. Society is assumed to be interested in maximising expected long-run economic yield in steady state.[4] In other words, the interest is in maximising the sum of expected resource rents, subject to the restriction that the natural growth rate equals the sum of expected catches. The assumption regarding the individual cost function, $c_i(x, h_i)$, is that costs are linear in x and h_i up to a capacity limit $\underline{h}_i$.[5] It is assumed that $\delta c_i/\delta h_i > 0$ and $\delta c_i/\delta x < 0$. The choice variables are catches and stock size, see for example Neher (1990a). Therefore:

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3 The implication of this is that x* need not to be derived, when the variable tax rate and the fixed penalty is calculated. x* is only of interest if T_i (x) is to be calculated.

4 By focusing on steady-state, discussions of adjustment to equilibrium is excluded. If exogenous prices and linear cost functions are assumed the optimal adjustment path will be a bang-bang control, see Conrad and Clark (1991). If, for example, costs are assumed to be non-linear, a gradual adjustment to steady-state is optimal. An approximation to the optimal adjustment path in the non-linear case can be obtained by using a feed-back control, where the next period´s optimal stock size is related to current variables. An example of using a feed-back rule is to be found in Sandal and Steinshamn (1997). Theoretically, there is nothing wrong with calculating optimal compliance taxes, as proposed in this paper, by using feed-back rules. However, the fundamental principle is more easily illustrated by restricting attention to the steady-state equilibrium. A further restriction is that the discount rate is assumed to be zero. In most advanced fishery economics society is assumed to maximise present value of future resource rents, see Clark and Munro (1978). Optimal stock exploitation can be given a capital theoretical interpretation and optimal control theory can be used to solve the problem. As with the discussion of adjustment toward steady-state equilibrium, it is possible to construct compliance taxes that include discounting. However, in order to avoid unnecessary complications, this analysis focuses on the long-run economic yield.

5 The assumption about the cost function may be seen as arbitrary, but is selected in order to make the calculations with expected values as simple as possible. Furthermore a cost function

$$\text{Max} \sum_{i=1}^{n} (E_{Si}(ph_i - c_i(x, h_i))) \tag{2}$$

s.t.

$$E_{Si}(G(x) - \sum_{i=1}^{n} h_i) = 0 \tag{3}$$

where:

p is an exogenous price.

G(x) is the natural growth rate. It is assumed that $G'(x) > 0$ for $x < x_{MSY}$ and $G'(x) < 0$ for $x > x_{MSY}$. Furthermore it is assumed that $G''(x) < 0$.

E_{Si} is an expectation operator for society with respect to fisherman i.

An implication of the maximisation procedure is that $G'(x^*) < 0$, because $\delta c_i/\delta x < 0$.[6]

Because of the assumed linearity of the objective function the maximisation problem may be written as:[7]

$$\text{Max} \sum_{i=1}^{n} (pE_{Si}(h_i - c_i(x, E_{Si}(h_i)))) \tag{4}$$

s.t.

$$G(x) - \sum_{i=1}^{n} E_{Si}(h_i) = 0 \tag{5}$$

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with a capacity limit is used in Conrad and Clark (1991). However, the assumption is by no means critical, and it is theoretically possible to work with a more general cost function.

6 Since $\delta c_i/\delta x < 0$, the derivative of the aggregated cost function with respect to stock size will also be negative, and $G'(x^*) < 0$.

7 If x is a stochastic variable, a rule is that $E(a + bx) = a + bE(x)$.

(4) and (5) may be solved with a standard Lagrange method.[8] However, because the paper wishes to compare the optimal solution with the model for fishermen behaviour, another method is used. In this method (5) is solved to yield:

$$x = M(E_{Si}(h_i), \mathbf{E_{S-i}(h_{-i})}) \tag{6}$$

where $\mathbf{E_{S\text{-}i}(h_{\text{-}i})}$ is a vector consisting of all other fishermen's expected catches. (6) is an expression for how the steady-state stock is related to expected catches. Using $M(E_{Si}(h_i), \mathbf{E_{S\text{-}i}(h_{\text{-}i})})$, a biological response function $\delta M/\delta E_{si}(h_i)$ may be constructed. The biological response function indicates how the steady-state stock responds to changes in expected individual catches. In optimum it will be the case that $\delta M/\delta E_{si}(h_i) < 0$.

Substituting (6) into (4) yields the following maximisation problem:

$$\text{Max} \sum_{i=1}^{n} (pE_{Si}(h_i) - c_i(M(E_{Si}(h_i), \mathbf{E_{S-i}(h_{-i})}), E_{Si}(h_i))) \tag{7}$$

The first-order conditions are:[9]

$$p - \frac{\delta c_i}{\delta E_{Si}(h_i)} - \frac{\delta c_i}{\delta M}\frac{\delta M}{\delta E_{Si}(h_i)} - \sum_{i \neq j} \frac{\delta c_j}{\delta M}\frac{\delta M}{\delta E_{Si}(h_i)} = 0 \text{ for } i = 1,\ldots,n \tag{8}$$

$p - \delta c_i/\delta E_{si}(h_i)$ is the expected marginal resource rent, and the marginal resource rent will be positive in optimum. This occurs before the capacity limit. $\delta c_i/\delta M \; \delta M/\delta E_{si}(h_i) + \sum \delta c_j/\delta M \; \delta M/\delta E_{si}(h_i)$ is equal to the expected marginal user cost of the stock. This can be seen if (4) and (5) are maximised by using a standard Lagrange method. The first-order condition for catches can be set equal to (8), and the result is reached so that $\lambda = \delta c_i/\delta M \; \delta M/\delta E_{si}(h_i) + \sum \delta c_j/\delta M \; \delta M/\delta E_{si}(h_i)$, where λ is a user cost for the fish stock. The expected marginal user cost contains two effects. Firstly, increased catches will decrease the steady-state stock

8 Thereby n + 2 equations and n + 2 unknowns is obtained. In this way it is seen why maximisation with respect to x is necessary.

9 It is assumed that $\delta E_{si}(h_i)/\delta h_i = 1$. This assumption is also adopted in Segerson (1988).

and thereby decrease the marginal cost reduction of the stock for fisherman i. $\delta c_i/\delta M \ \delta M/\delta \ E_{s\,i}(h_i)$ captures this effect. Secondly, increased catches for fisherman i will decrease the marginal cost reduction of the stock size for all fishermen other than i. $\sum\delta c_j/\delta M \ \delta M/\delta E_{s\,i}(h_i)$ captures this effect.

2.2. Fisherman behaviour

In this model, it is assumed that the stock size, not catches, is a stochastic variable. The reason for this assumption is that the stock size depends on the collective actions of the fishermen. Furthermore, it is not reasonable to make catches a stochastic variable – the fisherman must be assumed to know their own illegal and legal landings. There is thus a difference between the information structure assumed in Segerson (1988) and the information structure in this paper. Segerson (1988) operates with one variable that is stochastic for both actors. Here, stock size is stochastic for the fishermen and individual catches for the society. The difference in information structure reflects the fact that different policy problems are analysed.

The stock size is governed by a random variable, μ, which is submitted in what follows. Furthermore, it is assumed that the fishermen maximise the expected resource rent minus taxes (the expected net resource rent). An assumption regarding the fish stock is also necessary. Since the regulator taxes the stock, it is reasonable to assume that the stock size is not an exogenous variable as assumed in fisheries economics. One solution could be to let the maximisation take place over h_i and x. However, x is not a traditional endogenous variable, since it depends on the collective actions of the fishermen. Instead, a function for fisherman i relating stock to catches is postulated ($N_i(h_i, \mathbf{h_{-i}})= E_{Fi}(x)$, where E_{Fi} is an expectation operator for fishermen i). $N_i(h_i, \mathbf{h_{-i}})$ is an expression for how fishermen i perceive that the expected stock size is influenced by catches. An example of $N_i(h_i, \mathbf{h_{-i}})$ may be found in the formulation used in Jensen and Vestergaard (1999), where maximisation of the net resource rent occurs subject to the restriction $G(x) - h_i = 0$. Jensen and Vestergaard include the restriction due to altruistic preferences. Here it is included due to the fact that the regulator taxes the fishermen on the basis of the fish stock. Arnason (1990) operates with a model that is similar to this model, since the fishermen includes a resource restriction. However, Arnason assumes that $M(h_i, \mathbf{h_{-i}}) = N(h_i, \mathbf{h_{-i}})$, so the model presented here is more general, since a possibility is that $M(h_i, \mathbf{h_{-i}}) \neq N(h_i, \mathbf{h_{-i}})$. Furthermore, the stock tax analysed in this paper is a good argument for the assumption that the fishermen includes a resource restriction. $\delta N_i/\delta h_i$ is fisherman i´s perceived biological response and it is assumed that $\delta N_i/\delta h_i < 0$.

Since stock taxes are studied as an alternative to a control policy, a control policy can be excluded. The implication of this is that the fishermen in principal are free to choose their catches. In other words, the fishermen can exceed the total quota, as they will. Let us assume that the fisherman receives the same price for all landings. With expected net resource rent as the objective for fisherman i, and the assumed linearity of the objective function, the maximisation problem is:

$$\mathrm{Max}(ph_i - c_i(E_{Fi}(x), h_i) - E_{Fi}(T_i(x))) \tag{9}$$

s.t.

$$E_{Fi}(x) = N(h_i, \mathbf{h_{-i}}) \tag{10}$$

(9) can be rewritten. Let us call $\pi_i(E_{fi}(x), x^*)$ fisherman i's perceived probability that the expected stock is larger than the optimal stock. It must be expected that $\delta\pi_i/\delta E_{Fi}(x) > 0$. From (1) the expected total tax for fisherman i is:

$$E_{Fi}(T(x)) = t_i x^* - t_i E_{Fi}(x) + k_i(1 - \pi_i(E_{Fi}(x), x^*)) \tag{11}$$

Substituting (11) into (9), and (10) into (9), yields the following maximisation problem:

$$\mathrm{Max}(ph_i - c_i(N_i(h_i, \mathbf{h_{-i}}), h_i) - (t_i x^* - t_i N_i(h_i, \mathbf{h_{-i}}) + k_i(1 - \pi_i(N_i(h_i, \mathbf{h_{-i}}), x^*)))) \tag{12}$$

The first-order condition with Cournot-Nash expectations is:

$$p - \frac{\delta c_i}{\delta h_i} - \frac{\delta c_i}{\delta N_i}\frac{\delta N_i}{\delta h_i} + (t_i + k_i \frac{\delta \pi_i}{\delta N_i})\frac{\delta N_i}{\delta h_i} = 0 \qquad (13)$$

Neglect for a moment the tax component in order to interpret the first-order condition and compare the condition with the social optimal condition. In this case it must be assumed that $\delta N_i/\delta h_i = 0$ – the fisherman neglect the resource restriction. Now the fisherman will catch where the marginal resource rent ($p - \delta c_i/\delta h_i$) is zero. This occurs at the capacity limit, $\underline{h}$. From before $h_i^* < \underline{h}$ and the social optimal individual catch is less than the catch the fisherman wants. Therefore, a tax is imposed in order to secure that the individual optimal catch falls in line with the social optimal catch. $(t_i + k_i\, \delta\pi_i/\delta N_i)\delta N_i/\delta h_i$ is the expected marginal tax costs for the fisherman and $\delta c_i/\delta N_i\ \delta N_i/\delta h_i$ is the user cost of the fish stock as perceived by the fisherman. It is assumed that $\delta c_i/\delta M\ \delta M/\delta E_{si}(h_i) + \sum \delta c_j/\delta M\ \delta M/\delta E_{si}(h_i) > \delta c_i/\delta N_i\ \delta N_i/\delta h_i$. In other words the social user cost is larger that the user cost as perceived by the fisherman. A difference between the social optimal first-order condition and the first-order condition for the fisherman is that the effect that catches has on other fishermen is not reflected in (13). This captures a basic problem with illegal landings. Each individual fisherman does not take into account the effect that illegal landings have on other fishermen.

Now t_i and k_i that will secure the optimal individual catch and thereby remove the incentive to land illegally can be calculated.

2.3. *Optimal tax structure*

First $Q = \delta c_i/\delta N_i\ \delta N_i/\delta h_i - \delta c_i/\delta M\ \delta M/\delta E_{si}(h_i) - \sum \delta c_j/\delta M\ \delta M/\delta E_{si}(h_i)$ is defined. Q can be said to measure the marginal net expected social benefit of having the fisherman exceeding the optimal catch (illegal landings). As mentioned above there will be a difference between the expected user costs for fisherman and society. $\delta c_i/\delta N_i\ \delta N_i/\delta h_i – \delta c_i/\delta M\ \delta M/\delta/E_{si}(h_i) - \sum \delta c_j/\delta M\ \delta M/\delta E_{si}(h_i)$ captures this effect and the difference is negative. Therefore, there is an expected net social cost associated with having the fisherman exceeding the optimal catches through illegal catches.

Note now that $\delta c_i/\delta h_i = \delta c_i/\delta E_{si}(h_i)$ because of the assumed linearity of the cost function. By equating (13) and (8) the result is reached that the tax may be set in four ways to secure the optimal catch and thereby compliance with the total quota:

$$\begin{cases} \text{a.} \quad k_i = 0 \text{ and } t_i = \dfrac{Q}{\dfrac{\delta N_i}{\delta h_i}} \\ \text{b.} \quad k_i = \dfrac{Q}{\dfrac{\delta \pi_i}{\delta N_i}\dfrac{\delta N_i}{\delta h_i}} \text{ and } t_i = 0 \\ \text{c.} \quad k_i \text{ arbitrary and } t_i = \dfrac{Q - k_i \dfrac{\delta \pi_i}{\delta N_i}\dfrac{\delta N_i}{\delta h_i}}{\dfrac{\delta N_i}{\delta h_i}} \\ \text{d.} \quad k_i = \dfrac{Q - t_i \dfrac{\delta N}{\delta h_i}}{\dfrac{\delta \pi_i}{\delta N_i}\dfrac{\delta N_i}{\delta h_i}} \text{ and } t_i \text{ arbitrary} \end{cases} \tag{14}$$

The possible tax structures are as follows. Firstly, the fixed penalty may be set to zero and the variable tax rate to the marginal expected net social costs from exceeding the optimal catch divided by the fisherman's biological response. The fisherman´s biological response must be included since the tax influence catches though out the stock effect. Secondly, the variable tax rate may be set to zero and the fixed penalty to Q divided by the marginal probability change multiplied by $\delta N_i/\delta h_i$. Thirdly, the fixed penalty may be set arbitrary and t_i to the expected marginal net social cost minus the fixed penalty multiplied by the marginal probability change times the fisherman biological response divided by $\delta N_i/\delta h_i$. Fourthly, the variable tax rate may be set arbitrary and the fixed penalty to Q minus the variable tax rate multiplied by the fisherman biological response divided by the marginal probability change multiplied by $\delta N_i/\delta h_i$. Segerson

(1988) also arrives at a tax formula with four possibilities. However, a difference is that the response functions is reflected in the tax in this paper. The reason for this is restrictions on the maximisation problems.

Note that the tax structure eliminates free- riding. To see this, let us concentrate on tax structure a, and assume full information so that the expected values vanish in the tax formula. In this case:

$$t_i = \frac{\frac{\delta c_i}{\delta N_i}\frac{\delta N_i}{\delta h_i} - \frac{\delta c_i}{\delta M}\frac{\delta M}{\delta h_i} - \sum_{i \neq j}\frac{\delta c_j}{\delta M}\frac{\delta M}{\delta h_i}}{\frac{\delta N_i}{\delta h_i}} \tag{15}$$

From (15) it is seen that the fishermen pay on the basis of the difference in user costs. Therefore the fisherman also pays for the damage that he imposes on the other fishermen and thereby the full marginal costs that illegal landings generate. In this way free riding is eliminated and compliance with the total quota is ensured – the incentive to illegal landings is avoided. If a fixed penalty is included, k_i does not distort the marginal incentives, so free-riding is still eliminated. In the more general case, with asymmetric information, free-riding is also eliminated, since the fisherman pay on the basis of the full marginal costs that illegal catches generate. These results are analogous to the result in Segerson (1988).

On the basis of (15) a criticism of the suggested tax can be raised. It can be argued that the marginal cost reduction, due to a marginal increase in the stock size, will be little when calculated on an individual level ($\delta c_i/\delta N_i$ and $\delta c_i/\delta M$ will be numerically small). Therefore, the value of the variable tax rate will be so small that it does not influence marginal incentives to exceed the optimal catch. For this reason the tax works best when the fishery is restricted to a limited number of fishermen. Therefore, the simulation results in section 3 are conducted for cod in the Kattegat. However, this criticism is not correct. When $\delta c_i/\delta N_i$ and $\delta c_i/\delta M$ is numerically small the biological response for fisherman i ($\delta N_i/\delta h_i$) will also be numerically small. In other words, when the stock size does not have much influence on the fisherman's profit, the fisherman will not take much account of the effect that catches have on stock size. This effect will tend to make the variable tax rate larger and therefore there are two effects of opposite directions. It can therefore be concluded that when comparing a low and high numerical value of $\delta c_i/\delta N_i$ and $\delta c_i/\delta M$, nothing definite can be said about t_i, because of differences in $\delta N_i/\delta h_i$.

3. Simulation results

Now some simulation results for cod in the Kattegat are presented. The reason for selecting cod in the Kattegat is that it is a relativly small and restricted fishery. Concentration is put on tax structure a and full information is assumed. The interest is to get a rough indicator for the magnitude of the variable tax rates.[10] For this reason individual variable tax rates have been calculated for six vessel groups:

- Netters under 20 GT.
- Netters over 20 GT.
- Danish Seiners.
- Trawlers under 50 GT.
- Trawlers between 50 GT and 199 GT.
- Trawlers over 200 GT.

10 In principle an interest could also be to calculate total tax costs. This would, however, not be reasonable for the following reasons. With the assumed non-linear cost function a gradual adjustment to x* will be optimal. Therefore a year must be selected where x is close to x*. For cod in the Kattegat, a logistic growth function has been estimated on the basis of stock size and aggregated catches reported in appendix 1. This yields K = 170496 tonnes (see appendix 1) and therefore x_{MSY} = 85248 tonnes. Since $F'(x^*) < 0$, $x^* > 85248$ tonnes, but the actual stock size is of maximum 44 856 tonnes. Therefore the actual tax costs will be seriously overestimated. This conclusion holds for another reason. The procedure in section 2 was that the regulator announced a tax formula ((1) and (15)) at the start of the year and then collected taxes based on observable variables at the end of the year. By using this procedure society secures that x are close to x* - in theory x = x* and total tax revenue for society will be zero. By using actual stock sizes to calculate total tax costs, the effect that announcement of a tax formula would have on x, is excluded.

Individual variable tax rates have been calculated for the average vessel within these groups for 1971-1998. If the vessels are assumed to be homogenous within these groups, the taxes are also variable tax rates for the other vessels in the groups. Six groups have been selected since an interest is in focussing on the size of the tax difference that eliminates free-riding.

It may be concluded that the fishermen face a variable tax, not a variable subsidy, every year. In appendix 1 a logistic growth function is estimated and K = 170496 tonnes. Now x_{MSY} = 85248 tonnes and in optimum $G'(x^*) < 0$, so $x^* >$ 85248 tonnes. But x is in the period 1971 –1998 at maximum 44856 tonnes, so $x^* > x$.

Some assumptions have been adopted in order to keep the simulations simple. A more general cost function is introduced. It is assumed that $\delta c_i/\delta h_i > 0$, $\delta^2 c_i/\delta h_i^2 > 0$, $\delta c_i/\delta x < 0$, $\delta^2 c_i/\delta x^2 > 0$ and $\delta^2 c_i/\delta h_i \delta x < 0$. Furthermore, it is assumed that there is full information for both actors, and that $N_i(h_i, \mathbf{h_{-i}}) = s\, M(h_i, \mathbf{h_{-i}})$ with $s \leq 1$. s = 1 is the case described in Arnason (1990), but s < 1 allow for the fishermen to take some notice of the biomass growth constraint. This will result in larger catches and hence illegal landings. For cod in the Kattegat four cases have been simulated:

- s = 1.
- s = 0.8.
- s = 0.6.
- s = 0.4.

The simulations require knowledge of an individual cost function. The following cost function for cod have been calibrated:

$$c_i(x, h_i) = l_i \alpha_i + \frac{l_i \beta_i h_i^2}{x} \qquad (16)$$

Appendix 1 contains all the details regarding the calibration including the empirical model for the calibration of the parameters, and the data is also presented in appendix 1. Table 1 summarises the results.

Table 1: The calibration results

Group	**$l_i a_i$ (1000kr/tonnes)**	**$l_i b_i$ (1000kr/tonnes)**
Netters under 20 GT	150.07	2174.822
Netters over 20 GT	426.456	918.013
Danish Seiners	198.51	1575.591
Trawlers under 50 GT	195.75	869.868
Trawlers between 50 GT and 199 GT	233.29	744.623
Trawlers over 200 GT	31.820	4305.97

Call n_i the number of vessels in group i. Now the variable tax formular for an individual vessel in group i is:

$$t_i = \frac{\frac{\delta c_i}{\delta N_i}\frac{\delta N_i}{\delta h_i} - n_i \frac{\delta c_i}{\delta M}\frac{\delta M}{\delta h_i} - \sum_{i \neq j} n_j \frac{\delta c_j}{\delta M}\frac{\delta M}{\delta h_i}}{\frac{\delta N_i}{\delta h_i}} \qquad (17)$$

Now the simulation results can be presented, see figure 2 - 7.

Figure 2: Netters under 20 GT

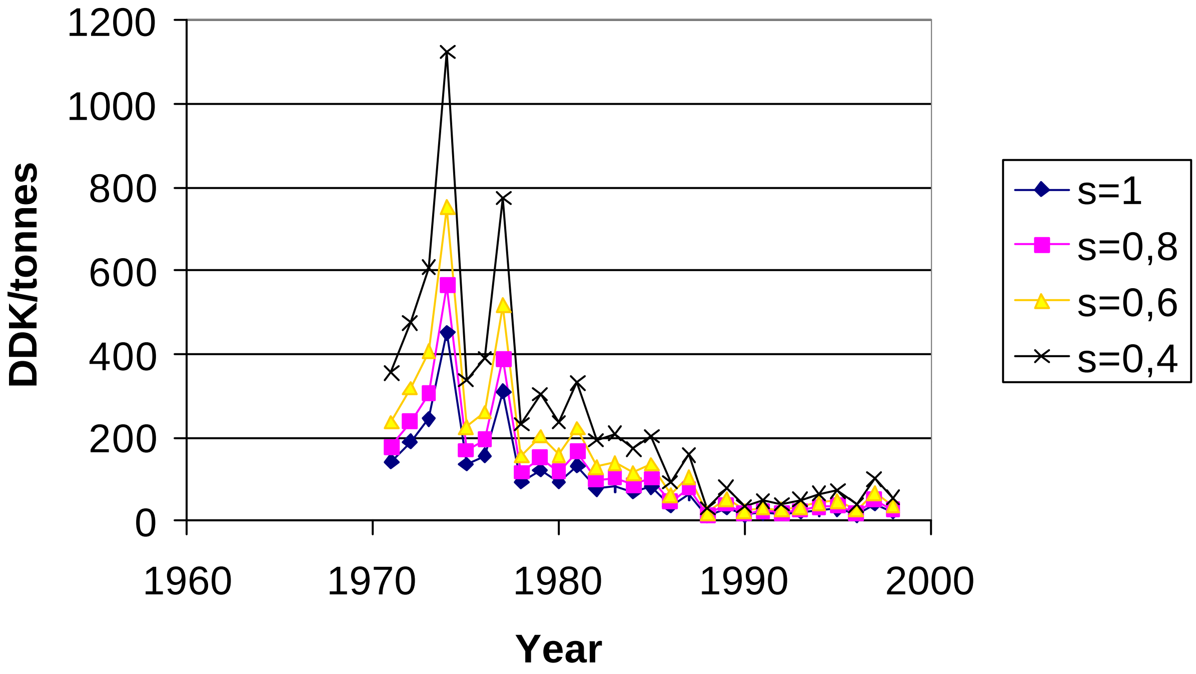


Figure 3: Netters over 20 GT

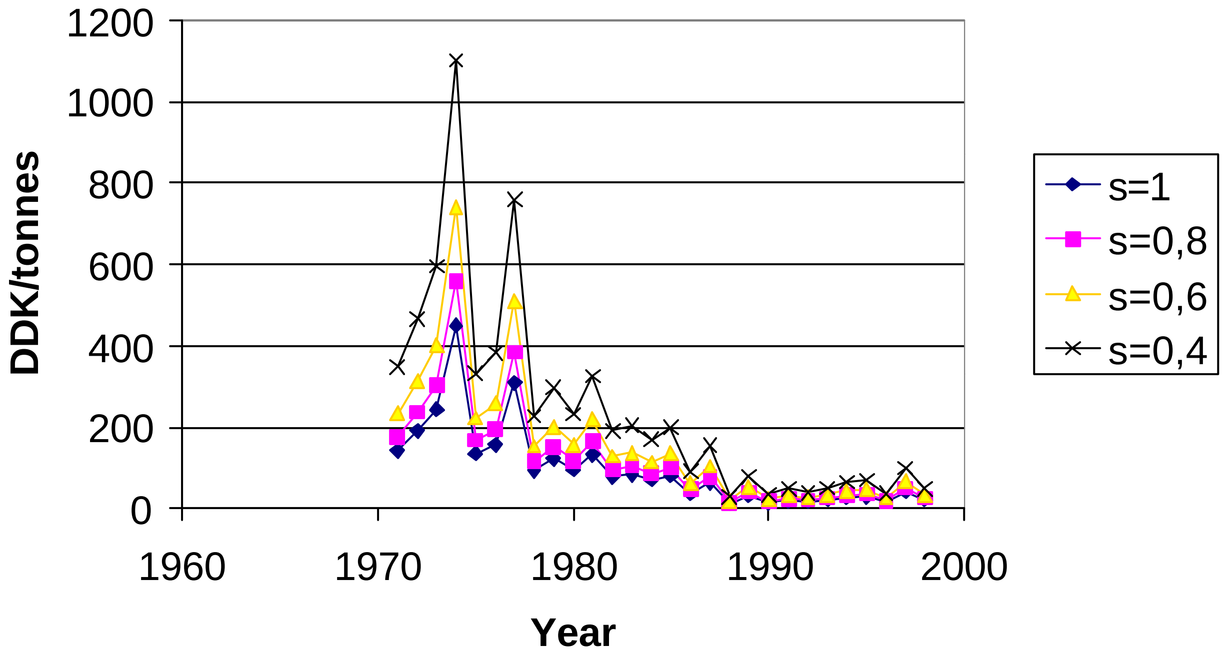


Figure 4: Danish Seiners

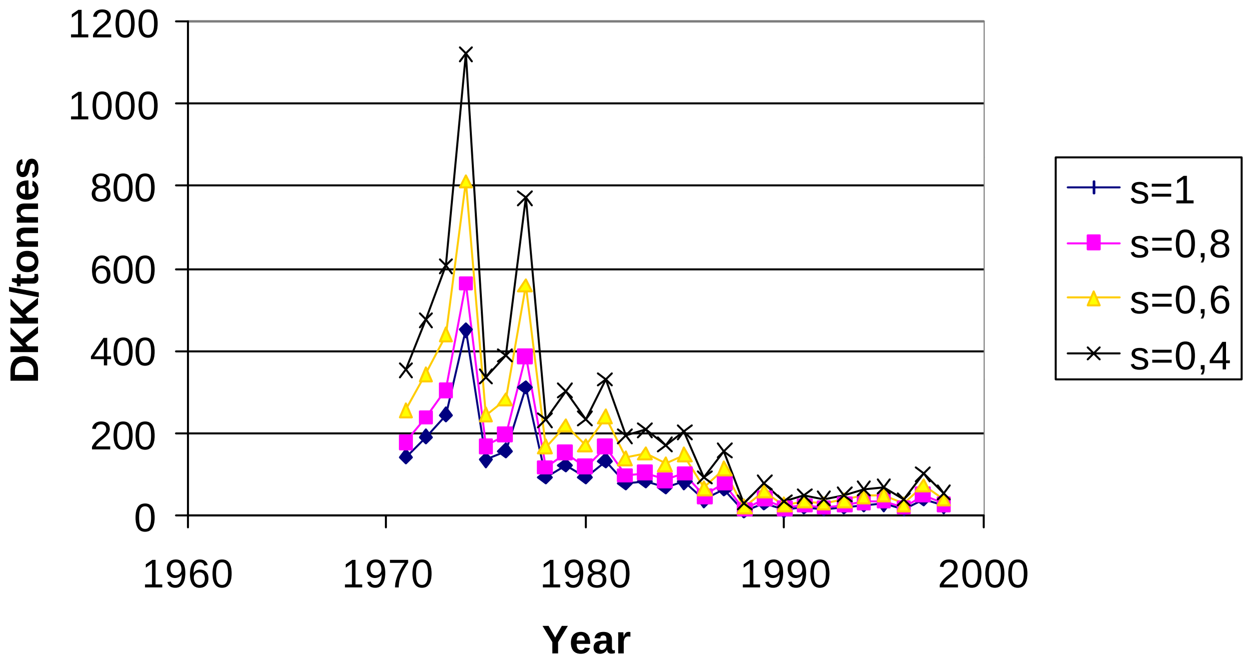


Figure 5: Trawlers under 50 GT

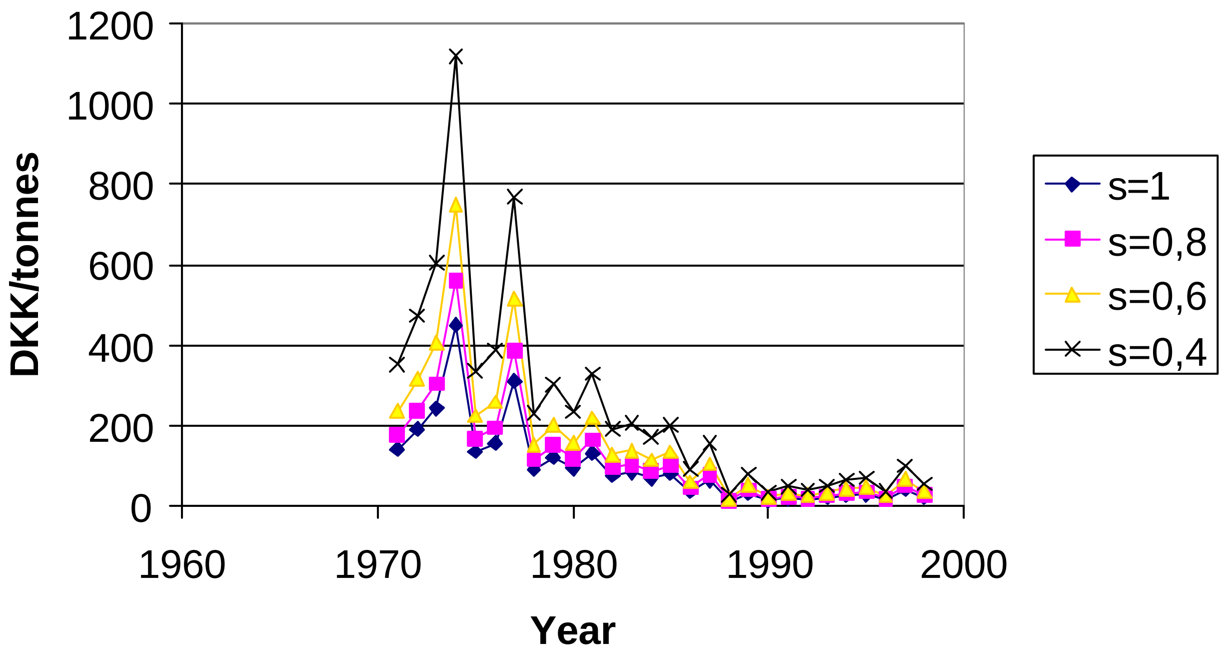


Figure 6: Trawlers between 50 GT and 199 GT

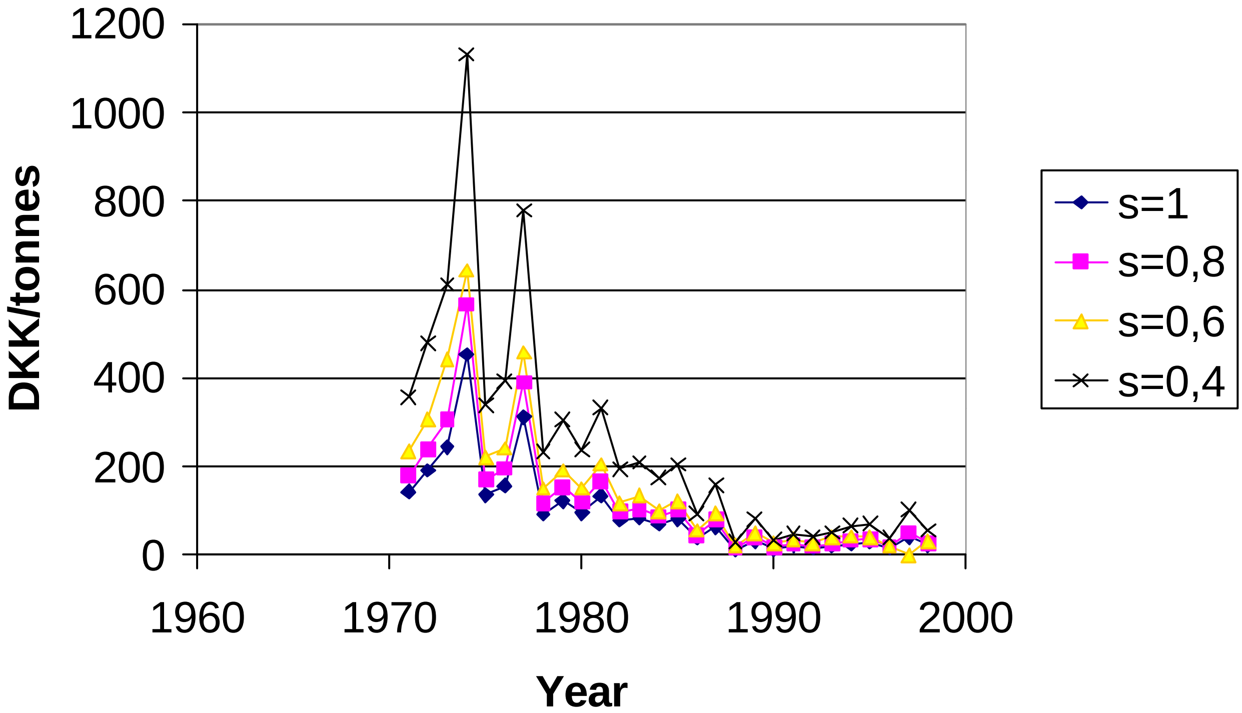
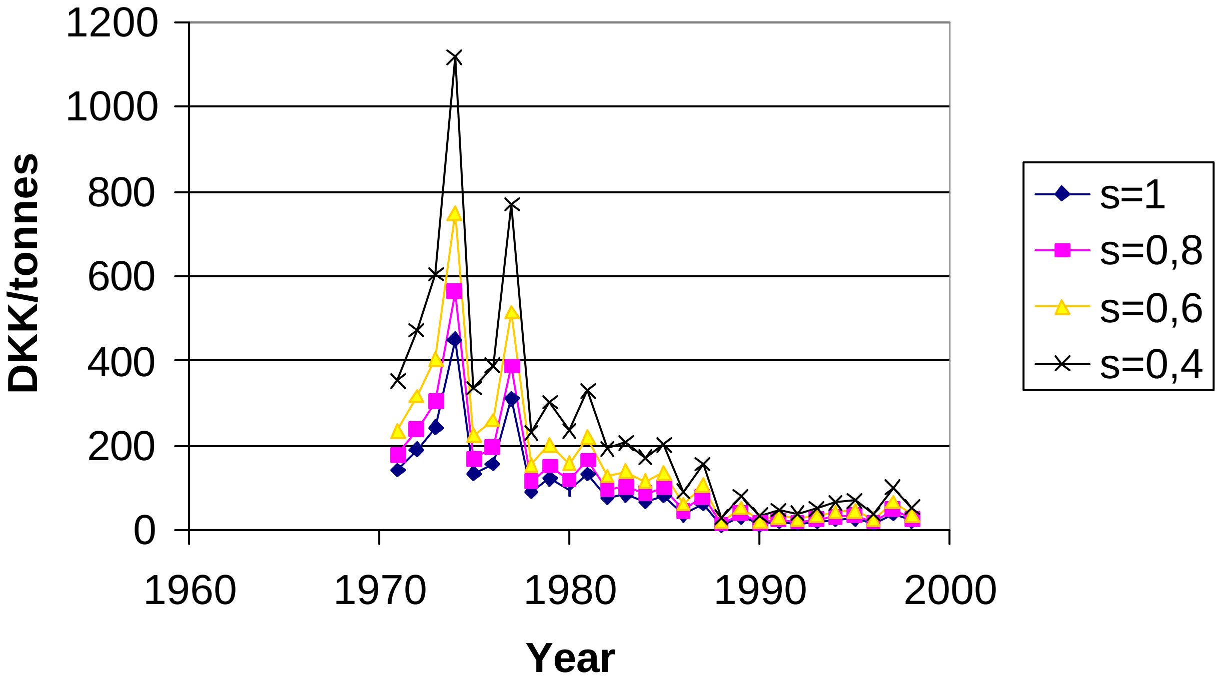


Figure 7: Trawlers over 200 GT



A striking feature is that the variable taxes rates are low compared to the sales price – maximum 1200 DKK. per tonnes the actual stock size is below the optimal stock size.[11] This suggests that the tax is potentially useful. It is seen that if s is low, t_i is high. This result is not surprising. If s is low, the market failure will be larger, and the variable tax rate must be large. The variation in taxes over time can be explained by variations in h_i and $M(h_i, \mathbf{h}_{-i})$. By differenting the tax function it can be shown that if catches is increased, the variable tax will also increase. Furthermore if $M(h_i, \mathbf{h}_{-i})$ is increased, the variable tax rate will decrease. These facts explains why the variable tax rate decreases over time. Note, however, that the proportion a vessel catch of the total catch is fixed at the 1997 level because of the lack of time series for h_i. The variation in variable tax rates between vessel groups tends to eliminate free-riding. The difference is very low, which could indicate that a uniform tax could be used. However, the simulation results are based on simple assumptions about the individual biological response function.

To sum up, the incentive scheme has potential application as a solution to compliance problems associated with illegal landings within a total quota system. However, the following discussion points highlight some problems with the scheme.

4. Discussion

Some aspects of the incentive scheme proposed here must be discussed further. It is a well known fact that fishermen are opposed to taxes since at least a part of the resource rent is exhausted, see Anderson (1986). The same conclusion applies to the mechanism discussed here, if the actual stock size is below the optimal stock size. Therefore, taxes has traditionally been seen as impossible within the fishery. Clark (1990) proposes a combination of a tax system and a system of ITQs to secure a fair sharing of the resource rent between society and the fishermen. Another solution could be to pay back at least a part of the collected resource rent to the fishing industry as a lump-sum transfer.

11 As already mentioned calculations of total taxes are meaningless.

A criticism of Segerson's mechanism has been that it does not secure budget-balance. This criticism is part of the motivation for the work by Xepapadeas (1991) and Govinsdasmy *et al* (1994) on non-point pollution. Xepapadeas proposes a random penalty mechanism to the solution of non-point pollution problems, while Govinsdasmy *et al* suggest an environmental ranking tournament. Even though it is relevant to discuss the environmental ranking tournament and the random penalty mechanism for a renewable resource, a fairly simple solution to the budget-balanced problem is to pay back the social benefit from falling in line with the optimal catches to the industry. Thereby, budget-balance can be secured.

Furthermore the information requirements of the proposed tax mechanism could be discussed. This point is part of the motivation for the previously mentioned work by Xepapadeas and Govinsdasamy *et al*. Within fisheries economics, taxes has traditionally been criticised for posing to many information requirements, see Arnason (1990). The tax structure proposed here raises even greater information requirements, since society at minimum must have information about individual biological responses. This information can be obtained in surveys, but it is also possible to reduce the information requirements by adopting simplifying assumptions as in the simulation study. However, the information demands is in practise not larger than the necessary information needed when the ambition is to regulate in an optimal fashion. Note also that the increased information requirements are due to the fact that more realistic assumptions about the information structure are allowed. In other words, the paper is conducted within what Russell (1994) calls complex regulation. Under complex regulation more realistic discussions of regulatory regimes are allowed by dropping some of the simplifying assumptions traditionally used. The price of the increase in reality is increased complexity. The issue of complex regulation arises in another way. The regulatory structure that is proposed here is complex, since it combines the use of total quotas and taxes. However, it must be remarked that the regulatory structure within the EU fisheries is at least as complex, see Jensen (1999) and Holden (1996).

The last point that must be discussed is the assumption that fishermen react to the stock tax by taking some account for their effect on the stock. If the fishermen do not react in this way the tax would be ineffective – the fishermen would interpret it as a lump sum tax, which does not influence the marginal incentive to catch illegally for example.

5. Conclusion

In this paper an economic incentive scheme as a solution to problems associated with illegal landings is presented. The economic incentive scheme is based on the work of Holmstrom (1982) and Segerson (1988), and can be seen as an alternative to a control policy. Since there are problems associated with illegal landings, it is assumed that society has imperfect information about individual catches. The stock size is assumed to be observable and is used as a tax base. It is argued that the incentive scheme makes all individual catches observable and therefore the estimate of the stock size becomes more precise. If the actual fish stock is above the optimal stock fishermen i receive a subsidy equal to the difference in stocks multiplied by a variable individual subsidy rate. In the case where the actual fish stock is below the optimal stock, society taxes the fishermen. The total tax is equal to the difference in stocks multiplied by a variable tax rate plus an individual fixed penalty. By the right selection of the individual tax/subsidy rate and the fixed penalty optimal individual catches can be secured. Note also that free-riding is eliminated since the total marginal social cost of exceeding the individual optimal catch is the basis for the calculation basis of the tax/subsidy. Thereby, compliance with the TAC is reached. Simulations for cod in the Kattegat reveal a striking result. The variable tax rates are in some cases only 3% of the sales price. Note, however, that the results of the simulations are very rough estimates of the actual tax rates.

Two assumptions are worth repeating. Firstly, the analysis is based on maximising economic yield in steady-state. Therefore, the subjects of discounting and adjustment toward equilibrium are excluded. Theoretically, for example, feedback rules could be used in the calculations of the economic incentive. This constitutes an area for future research. Secondly, it is postulated that the individual fisherman reacts to a stock tax by taking some account of the resource restriction. This assumption is most likely to be fulfilled if the total quota is allocated to small groups of fishermen.

In the introduction it was pointed out that by-catches and discard also pose problems with compliance to total quotas. The tax mechanism can also solve these problems, and this also constitutes an area for future research. Another promising area for future research is to allow for non-linear objective functions.

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Appendix 1: Calibration of the cost function and estimation of a growth function

In this appendix the model on which the cost functions is calibrated is presented. Furthermore, a logistic growth function is estimated and an expression for $M(h_i, \mathbf{h}_{-i})$ is found.

1.a Calibration of the cost function

First to the model used for calibrating the cost functions. A model from Vestergaard and Jensen (2000) is adopted. The profit function for fisherman i is:

$$\pi_i(h_i, x) = p_i h_i - c_i(x, h_i) \tag{1}$$

where p_i is a constant price.

The cost function is assumed to be linear in effort:

$$c_i(x, h_i) = l_i e_i(h_i, x) \tag{2}$$

where:

l_i is the cost per unit of effort.

$e_i(h_i, x)$ is a effort function which specifies the effort needed to take a given catch with a given stock size.

The effort function is assumed to be:

$$e_i(h_i, x) = \alpha_i + \frac{\beta_i h_i^2}{x} \tag{3}$$

Inserting (3) into (2), and (2) into (1), yields:

$$\pi_i(h_i, x) = p_i h_i - l_i \alpha_i - \frac{l_i \beta_i h_i^2}{x} \tag{4}$$

Data is only obtainable for three years. Therefore data for 1997 is used to calibrate the parameters $l_i\alpha_i$ and $l_i\beta_i$.

There is data on average prices (p_i), costs (s_i) and harvest (h_i). Hence an LP-model can look like:

$$\text{Max } ((p_i - s_i) h_i) \tag{5}$$

s.t.

$$h_i \le h_i \tag{6}$$

The constraint reflects that rations regulate the cod fishery.

The first order condition of the LP model is:

$$p_i - s_i - \lambda_i = 0 \tag{7}$$

The first order condition of (4) is:

$$p_i - \frac{2 l_i \beta_i h_i}{x} = 0 \tag{8}$$

Combining these expressions gives:

$$\beta_i l_i = \frac{(\lambda_i + s_i) x}{2 h_i} \tag{9}$$

$$\alpha_i l_i = s_i h_i - \frac{\beta_i l_i h_i^2}{x} \tag{10}$$

By running the LP model, a value for λ_i are found. Together with estimates for h_i and x (table A.3), the parameters can be found.

Information about average prices is obtained from Anon (1997). The average price of cod is calculated from information on revenue and catches. The variable costs include all costs except depreciation and interest. The share of cod of the gross output is used to find the variable cost of cod. Table A.1 summarise the data.

Table A.1: Data for the calibration, 1997

	Netters under 20 GT	**Netters over 20 GT**	**Danish Seiners**	**Trawlers under 50 GT**	**Trawlers between 50GT and 199 GT**	**Trawlers over 200 GT**
Gross output, cod 1000DKK/ tonnes	368.4	1424.5	571.7	555.4	710.6	132.4
Catch cod Tonnes	34.9	105.3	50.9	67.5	82.7	14.8
Average price, cod, 1000DKK/ tonnes	10.6	13.5	11.2	8.2	8.6	8.9
Variable costs, 1000 DKK	670.8	2327.9	1820.9	1233.5	3059.6	7002.9
Share of cod	49.74	48.74	26.56	38.49	19.01	1.4
Variable cost, cod 1000 DKK	333.7	1134.6	483.6	474.8	581.6	98
Cost per tonnes, 1000 DKK	9.6	10.8	9.5	7	7	6.6

Source: Anon (1997)

The LP model provides the shadow prices in table A.2.

Table A.2: Shadow prices, 1000 DKK

	Netters under 20 GT	**Netters over 20 GT**	**Danish Seiners**	**Trawlers under 50 GT**	**Trawlers between 50 GT and 199 GT**	**Trawlers over 200 GT**
λ_I	1	2.7	1.7	1.2	1.6	2.3

Inserting these into (9) and (10), gives the estimates in the text.

1. b Estimation of a growth function

From Anon (1998) information about x and aggregated catches, h, for the period 1971-98 is available. Table A.3 reports these.

Table A.3: Stock size, aggregated catches and natural growth rate

Year	x, tonnes	h, tonnes	G(x), tonnes
1971	42372	15732	16985
1972	43625	17442	18673
1973	44856	18837	14996
1974	41015	21880	14667
1975	33802	15485	19293
1976	37710	16275	14467
1977	35902	20119	14479
1978	30262	13390	14924
1979	31796	14830	12205
1980	29171	13509	10209
1981	25871	15337	9876
1982	20410	12465	12869
1983	20814	12828	12873
1984	20959	11886	9958
1985	19031	12706	8575
1986	14900	9096	7306
1987	13110	11491	7890
1988	9509	5527	7320
1989	11302	8590	5879
1990	8592	5936	6833
1991	9489	6834	8374
1992	11029	6271	8160
1993	12918	7013	12829
1994	18734	7802	2942
1995	13874	8165	4322
1996	10031	6126	10416
1997	14321	9461	6934
1998	11794	6835	

Source: Anon (1998)

It is now possible to calculate a proxy for h_i in year y by the formula:

$$\left(\frac{h_{i1997}}{h_{1997}}\right)h_y \tag{11}$$

This time series is reported in table A.4.

Table A.4: Time series for individual catches

Year	Netters under 20 GT, tonnes	Netters over 20 GT, tonnes	Danish Seiners, tonnes	Trawlers under 50 GT, tonnes	Trawlers between 50GT and 199 GT, tonnes	Trawlers over 200 GT, tonnes
1971	58	175	85	112	138	25
1972	64	194	94	124	152	27
1973	69	210	101	134	165	29
1974	81	244	118	156	191	34
1975	57	172	83	110	135	24
1976	60	181	88	116	142	25
1977	74	224	108	144	176	31
1978	49	149	72	96	117	21
1979	55	165	80	106	130	23
1980	50	150	73	96	118	21
1981	57	171	83	109	134	24
1982	46	139	67	89	109	19
1983	47	143	69	92	112	20
1984	44	132	64	85	104	19
1985	47	141	68	91	111	20
1986	34	101	49	65	80	14
1987	42	128	62	82	100	18
1988	20	62	30	39	48	9
1989	32	96	46	61	75	13
1990	22	66	32	42	52	9
1991	25	76	37	49	60	11
1992	23	70	34	45	55	10
1993	26	78	38	50	61	11
1994	29	87	42	56	68	12
1995	30	91	44	58	71	13
1996	23	68	33	44	54	10
1997	35	105	51	68	83	15
1998	25	176	37	49	60	11

Now to some considerations regarding the growth function. The data for x is from 1/1 in a year and the data for h is from 31/12 in a year. It is therefore obtained that:

$$G(x_t) = x_{t+1} - x_t + h_t \tag{12}$$

The data serie for G(x) is also reported in table A.3. On the basis of the data in table A.3, a standard logistic growth function can be estimated:

$$G(x) = rx(1 - \frac{x}{K}) \tag{13}$$

where:

r is the intrinsic growth rate
K is the carrying capacity

Non-linear least square is used since parameters are correlated. The results is:

r = 0,54 (6,96)
K = 170496 (tonnes (1,79))

With:

$$R^2 = 0.51$$

Note that K is insignificant. The reason for this is that K is large compared to x.

1.c. An expression for M(h_i, $\boldsymbol{h}_{-i}$)

The steady state equation may be written as:

$$-\frac{rx^2}{K} + rx - \sum_{i-1}^{n} h_i = 0 \tag{14}$$

Solving with respect to x and concentrating on the largest root, since $F'(x^*) < 0$, yields:

$$M(h_i, \mathbf{h}_{-i}) = \frac{(r + (r^2 - \frac{4r(\sum_{i-1}^{n} h_i)}{K})^{0,5}}{\frac{2r}{K}} \tag{15}$$

$M(h_i, \mathbf{h_{-i}})$ is the function that is analysed in section 2.

Differentiating with respect to h_i yields:

$$\frac{\delta M}{\delta h_i} = -(r^2 - \frac{4r\sum_{i-1}^{n} h_i}{K})^{-0,5} \tag{16}$$

To calculate the variable tax rates reported in section 3, information is also needed about the number of vessels in the six groups. These are reported in table A.5.

Table A.5: The number of vessels fishing cod in Kattegat, 1997

	Netters under 20 GT	**Netters over 20 GT**	**Danish Seiners**	**Trawlers under 50 GT**	**Trawlers between 50 and 199 GT**	**Trawlers over 200 GT**
Number	61	3	32	113	32	1

Source: Fiskeridirektoratet (2000)

Now the variable tax rates can be calculated.

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