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Moral hazard problems in fisheries regulation: the case of illegal landings and discard

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Abstract

This paper treats illegal landings and discards of fish as a moral hazard problem that arises from individual catches that are unobservable to society, and hence are private information. A tax/subsidy mechanism taking into account the asymmetric information problem is formulated as a solution to problems of illegal landings and discards. 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.
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1. Introduction

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

From Fig. 1, it can be seen that the actual fishing mortality is generally much higher than the intended fishing mortality. This result is partly due to misreported landings and discard. Indeed, Svelle et al. (1997) claim that for cod in the North Sea, discards and illegal landings are 22% of the catch weight and 51% of the number of caught fish. Discards and illegal landings are also a major problem within the European Union (EU) (Commission (1992)), and at a global level, Alverson et al. (1994) show that illegal landings and discards pose

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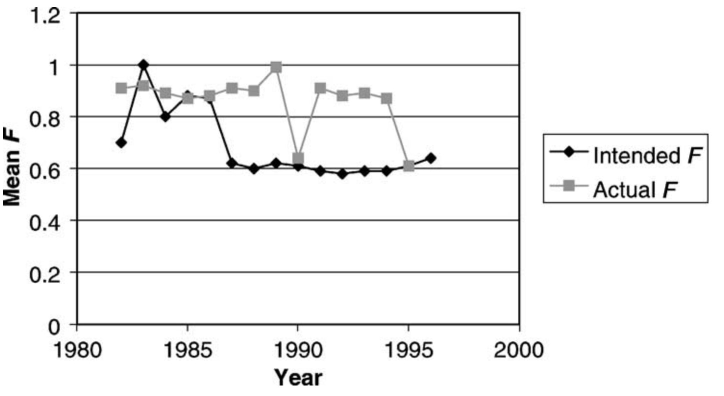

Fig. 1. Intended and actual fishing mortality, *F*, for North Sea cod. Source: Svelle et al. (1997).

problems. Banks et al. (2000) show that the fishermen perceive that illegal landings are the most unlikely non-compliance activity to be detected. The main purpose of a quota system is to conserve the resource stock, thus unreported catches undermine this purpose, and in turn threaten resource stocks and create low economic returns in the sector.

There is some confusion within the fisheries literature concerning the concepts of illegal landings, by-catches and discards.[1] Illegal landings can be defined as catches of fish that are landed and sold in contravention of fisheries regulations. By-catches are fish that are unintentionally harvested when fishing for targeted species, while discards are fish harvested but returned to the sea. Discards might include both targeted species and by-catches, while by-catches may or may not be discarded, and may or may not be included in illegal landings. High-grading is synonymous with discarding, since it involves deliberate dumping of caught fish at sea so as to maximize the gross returns per fishing trip.

In this paper, attention is restricted to illegal landings, even though the tax system analysed here can also be used as an incentive scheme to solve the problems associated with discarding. The problem of illegal landings is viewed as a problem that arises because individual catches cannot be observed.[2] 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 Segerson (1988). In both cases, in order to eliminate free riding an individual pays on the basis of the full damage an activity

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[1] We thank one anonymous referee for these definitions.

[2] Discards also make individual catches unobservable to society. It could be argued that the moral hazard problem manifests itself much more in terms of discarding than illegal landings. The reason for this is that various mechanisms exist in terms of monitoring landings, while it is more difficult to observe fishermen at sea. However, the tax mechanism suggested here can also be used for discards of catches of targeted species, but a parameter $\alpha < 1$ must be included in front of the fishing mortality due to catches, because some discarded fish survive. Furthermore, a similar tax mechanism can be used for discards of by-catches. However, in this case, two taxes are necessary. One tax must be used for discards of catches of targeted species and another tax must be used for discards of by-catches.

causes. However, there are two differences from Segerson (1988). First, the mechanism is simulated, and the simulation results show that the variable tax is surprisingly low compared to the sales price. Indeed, this paper can be seen as a first attempt to obtain estimates of a mechanism to solve non-point pollution problems. Second, a different information structure is assumed. Segerson (1988) assumes that one variable is unobservable to both actors. In this paper, individual catches are unobservable to society but observable to the fishermen. This difference is due to the different policy problems being analysed.

A single species assumption is adopted and a system where a total quota is distributed to fishermen as individual quotas is assumed in this paper. It can be argued that under a pure total quota system the fishermen have little incentive to conceal their landings. When the quota is filled, no fishing is allowed and a typical enforcement method is to require all vessels to stay at dock. It is for this reason that a total quota is assumed to be distributed as individual quotas in this paper. With individual quotas, compliance problems arise; see Copes (1986). Furthermore, nearly all EU countries distribute the EU determined total quota to fishermen as a form of individual quotas ranging from trip quotas to individual transferable quotas (ITQs); see for example Davidse et al. (1997).[3]

Some comments on the economic literature on discards 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. For example, 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 ITQs can cause high-grading when high-grading is not socially optimal. Arnason (1994) develops a dynamic model that explicitly considers different grades of fish to examine the catch discard problem. The study shows that in a differentiated fishery, discarding of catches 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 maximizing 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 discards 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

[3] The single species assumption may be argued to be inappropriate for the regulatory setting within for example the EU. In EU waters, there are numerous of total quotas, one for each species. However, the single species assumption is selected in order to keep the analysis as simple as possible, because viewing illegal landings as a moral hazard problem is a new research area, so it is therefore useful to avoid the complication that arises when working with multi-species models.

enforcement (see for example Andersen and Sutinen (1983), Sutinen and Andersen (1985), Milliman (1986), Anderson and Lee (1986) Anderson (1987, 1989), Neher (1990) Charles (1993) and Charles et al. (1999)). Two fundamental results are established. First, with costly enforcement, it will not be optimal to ensure complete compliance. Second, 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 response to the problems associated with illegal landings and discards have been such a policy all around the world. In the EU, the control policy is judged to be ineffective, see for example Holden (1996). 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 Sections 4 and 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. As mentioned in Section 1, the total quota is distributed to fishermen as individual quotas and a single species assumption is adopted. In the present paper, individual catches are assumed to be unobservable by society due to illegal landings, whereas, total catches are assumed to be observable by society due to measurement of the fish stock. This set up is similar to pollution by individual firms in the non-point pollution control literature; see Hanley et al. (1997) for an overview.[4] 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. First, the problem is also considerable in the measurement of pollution in the non-point pollution literature. Second, observable catches from part of 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 fishermen's private information about catches. Despite the fact that catches are made observable, there might still exist problems with obtaining a reliable measure of stock size, see Anon. (1999). These problems are, however, smallest for long lived species, and in what follows the problem with measurement of stock size is assumed away.

Segerson (1988) proposes a tax/subsidy mechanism as a solution to non-point pollution problems. This mechanism is analysed here and the mechanism is as follows:[5]

$$T_{it}(x_{t+1}) = t_{it}(x^*_{t+1} - x_{t+1}) \tag{1}$$

where x_{t+1} is the observable actual size of the fish stock at the end of the year; x^*_{t+1} the target stock size at the end of the year.

[4] Non-point pollution is defined as the case where pollution by individual firms cannot be measured.

[5] Segerson (1988) incorporates a fixed penalty if the aggregated pollution is above the standard. However, this fixed penalty is excluded in this paper.

T_{it} (x_{t+1}) is the tax function for fisherman i for the period between t and $t+1$. Note that the fish stock is the basis for the tax, since individual catches cannot be observed and t_{it} is the tax/subsidy rate, which can vary between fishermen, for period t.

Eq. (1) indicates that if the target stock size is below the actual stock size, the fisherman pays a tax, while the fisherman receives a subsidy $(T_{it}(x_{t+1}) < 0)$ if $x^*_{t+1} < x_{t+1}$.

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 collects the tax or pays the subsidy. Two interpretations of the tax are possible. First, society can announce x^*_{t+1}. In this interpretation, Eq. (1) becomes an alternative to a total quota policy. Second, on the basis of a growth function, the optimal aggregated catches, h^*_t, can be calculated and a total quota on h^*_t can be announced in combination with Eq. (1). In other words, both h^*_t and x^*_{t+1} 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. The system can be seen as an alternative to the system at work when the total quota is distributed to fishermen as individual quotas. Indeed, Wilen (2000) mentions that over 55 fisheries are managed by individual quotas and with these, compliance problems arise; see Copes (1986). However, in general, the system is an alternative to any regulated open access regime, see Homans and Wilen (1997).

In order to calculate t_i (Section 2.2) that secures optimal individual catches a model for social optimal individual catches is necessary[6] and this model assumes that an economic objective determine these catches.[7] When optimal catches are determined, a stochastic version of a management model from Clark (1990) is used. In this model the maximization problem is:[8]

$$\max E\left(\sum_{t=0}^{\infty}\sum_{i=1}^{n}\rho^t(ph_{it} - c_{it}(h_{it}, x_t, x_{t+1} - x_t))\right) \tag{2}$$

s.t.

$$G(x_t) - E\left(\sum_{i=1}^{n}(h_{it})\right) + x_t = x_{t+1} \tag{3}$$

where E is an expectation operator. This operator must be included because individual catches are unobservable due to illegal landings. Individual catches are assumed to be governed by a random variable, ε while ρ is a discount factor. h_{it} is the catch of fisherman i in the period between t and $t+1$ and h_t is the control variable. p is an exogenous price; x_t (state variable) the stock size at time t; x_{t+1} the stock size at time $t+1$. $G(x_t)$ is the natural growth function. The cost function for fisherman i is $c_{it}(h_{it}, x_t, x_{t+1} - x_t)$ at time t. It is assumed that $\partial c_{it}/\partial h_i > 0$, $\partial^2 c_{it}/\partial h_{it}^2 > 0$, $\partial c_{it}/\partial x_t < 0$, $\partial^2 c_{it}/\partial x_t^2 > 0$ and

[6] Later in the paper, it is shown why a model for social optimal individual catches is necessary.

[7] The interest is only in calculating t_i. The implication of this is that x^*_{t+1} need not to be derived (x^*_{t+1} is only of interest if T_{it} (x_{t+1}) is to be calculated).

[8] The formulation in this paper differs from the formulation in Pindyck (1984) because the natural growth rate is unobservable in Pindyck (1984) while catches is unobservable in this paper. However, in this paper, the stock size also moves according to a stochastic difference equation as in Pindyck (1984). The reason for this is x_{t+1} becomes uncertain because catches is governed by a random variable.

$\partial^2 c_{it}/\partial h_{it}\partial x_t > 0$. Note that the development in the stock size between $t+1$ and t is included in the cost function. This assumption can be deduced from the model in Clark (1990) for total quotas. Here the integral of the objective function is defined from $t = 0$ to the time when the quota is filled.

By substituting (3) into (2) and noting that $\partial x_{t+1}/\partial E(\partial h_{it}) = -1$ in the restriction, the following first-order condition holds for the optimal catch at time t for the period between t and $t+1$:

$$p = E\left(\frac{\partial c_{it}}{\partial h_{it}}\right) + E\left(\frac{\partial c_{it}}{\partial x_{t+1}} + \sum_{j\neq i}\frac{\partial c_{jt}}{\partial x_{t+1}}\right) \quad (4)$$

Alternatively, the problem in (2) and (3) may be solved by the Lagrange-method. By setting the solution arrived at with this method equal to (4), the expected user cost for fisherman i in period t is given by $-E(\partial c_{it}/\partial x_{t+1} + \sum_{j\neq i}\partial c_{jt}/\partial x_{t+1})$. The user costs contains two components. First, the loss in cost reductions due to stock size for fisherman i in future periods that arise as a result of illegal landings by fisherman i is included. Second, the user cost includes the loss in cost reductions due to stock size in future periods for all other fisherman as a result of illegal landings by fisherman i. Eq. (4) states that the marginal benefits (p) are set equal to the expected marginal social costs $(-E(\partial c_{it}/\partial h_{it} + \sum_{i\neq j}\partial c_{jt}/\partial h_{it}) + E(\partial c_{it}/\partial h_{it}))$.

In order to calculate the variable tax rate (Section 2.2.), a model for fishermen's behaviour is needed (Section 2.1).

2.1. Fishermen's behaviour

In this model, it is assumed that x_t and h_{it} are observable for the fishermen. 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 by both actors. Here, individual catches are only unobservable by society. The difference in information structure reflects the fact that different policy problems are analysed.

It is assumed that the fishermen maximize the resource rent minus taxes at time t. 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 is normally assumed in fisheries economics. One solution could be to let the maximization occur for h_{it} and x_t. However, x_t is not a traditional endogenous variable, since it depends on the collective actions of the fishermen and is beyond the control of individual fishermen. Instead, a function for fisherman i relating stock size at time $t+1$ to catches and the stock size at time t is postulated $N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) = x_{t+1}$, where $\boldsymbol{h}_{-it}$ is a vector of catches for all fisherman than other (i). $N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})$ is an expression for how fisherman i perceives that the stock size at time $t+1$ is influenced by catches. An example of $N_{it}(x_t, h_{it}, h_{-it})$ may be found in the formulation used in Jensen and Vestergaard (1999), where maximization of the net resource rent in steady state occurs subject to the restriction $G(x) - \sum_{i=1}^{n} h_i = 0$. Jensen and Vestergaard include the restriction because they assume altruistic preferences. Here it is included because the regulator taxes the fishermen on the basis of the fish stock. Arnason (1990) applies a model that is similar to this model, since the fishermen include a resource restriction. However, Arnason assumes that $N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})$ reflects the true resource restriction (the natural growth), so the model presented here is more general. Furthermore, the stock tax analysed in this paper is a good argument for the assumption that the fishermen include a resource restriction. $\partial N_{it}/\partial h_{it}$ is the perceived biological response for fisherman i and it is assumed that $\partial N_{it}/\partial h_{it} < 0$. Furthermore, it is assumed that $\partial^2 N_{it}/\partial h_{it}^2 > 0$ and $\partial^2 N_{it}/\partial h_{it}\partial x_t < 0$. On the basis of $N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})$, an important point can be deduced. Kolstad (2000) mentions that a Segerson mechanism works best in small groups, and this point can be easily seen in this model. If the number of fishermen is large, it is not likely that the fishermen will respond to a stock tax by taking resource conservation measures. Therefore, the stock tax works best when the fishery is small and for these reasons the simulations are conducted for cod in Kattegat.

Since stock taxes are studied as an alternative to a control policy, a control policy can be excluded. The implication of this is that, in principle, the fishermen are free to choose their catches. In other words, the fishermen can exceed the total quota. Assume that the fisherman receives the same price for all landings. With resource rent as the objective for fisherman i in the period between t and $t+1$ and h_{it} as the control variable, the maximization problem is:

$$\max(ph_{it} - c_{i_t}(x_t, h_{it}, x_{t+1} - x_t) - T_{it}(x_{t+1})) \tag{5}$$

s.t.

$$x_{t+1} = N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) \tag{6}$$

Assume now that the fishermen have an incentive to exceed the optimal catches for society. With this assumption, (5) can be rewritten. From (1) the total tax for fisherman i is:

$$T_{it}(x_{t+1}) = t_{it}x^*_{t+1} - t_{it}x_{t+1} \tag{7}$$

Substituting (6) and (7) into (5), yields the following maximization problem:

$$\max(ph_{it} - c_{i_t}(h_{it}, x_t, N_i(h_{it}, \boldsymbol{h}_{-it}, x_t) - x_t) - (t_{it}x^*_{t+1} - t_{it}N_i(h_{it}, \boldsymbol{h}_{-it}, x_t))) \tag{8}$$

The first-order condition with Cournot–Nash expectations is:[9]

$$p - \frac{\partial c_{it}}{\partial h_{it}} + t_{it}\frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial N_{it}}\frac{\partial N_{it}}{\partial h_{it}} = 0 \tag{9}$$

The tax component is to be ignored for a moment in order to interpret the first-order condition and compare the condition with the social optimal condition. In this case, it is reasonable to assume that $\partial N_{it}/\partial h_{it} = 0$. Now the fisherman will catch up to the point where the marginal resource rent $(p-(\partial c_{it}/\partial h_{it}))$ is 0. A tax is now imposed in order to ensure that the individual optimal catch falls in line with the socially optimal catch and $t_{it}\,\partial N_{it}/\partial h_{it}$ is the marginal tax cost for the fisherman, while $\partial c_{it}/\partial N_{it}\,\partial N_{it}/\partial h_i$ is the user cost as perceived by the fisherman. By comparing (4) with (9), the basic externality problem of illegal landings can

[9] From (9) it can be seen why a model for social optimal catches is necessary. The (9) can be combined for all fishermen to yield $h_{it} = f(t_{i1}, \ldots, t_n, x_t, x_{t+1})$, where h_t is aggregated catches. Now one equation with $n+1$ unknown is obtained. When policy makers set x_{t+1} equal to a target stock size, a problem of determining the individual tax rates that eliminates free riding (illegal landings) arises.

be seen. Fisherman i does not take into account the effect that illegal landings has on all other fishermen.

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

2.2. Optimal tax structure

First $Q = \partial c_{it}/\partial h_{it} - E(\partial c_{it}/\partial h_{it}) + \partial c_{it}/\partial N_{it}\,\partial N_{it}/\partial h_{it} - E(\partial c_{it}/\partial x_{t+1} + \sum_{j\neq i}\partial c_{jt}/\partial x_{t+1})$ is defined. Q can be said to measure the expected marginal net social benefit of having the fisherman exceed the optimal catch (illegal landings) and contains two effects. First, society's expectations with respect to the marginal costs may be wrong. Second, the difference in user costs of the fish stock is included. It must be expected that $Q < 0$ (the fishermen has an incentive to catch illegally).

By equating (4) and (9), the tax may be set such a way so as to ensure the optimal catch, and thereby compliance with the total quota:

$$t_{it} = \frac{Q}{\partial N_{it}/\partial h_{it}} \tag{10}$$

The variable tax rate is the expected marginal net social cost from exceeding the optimal catch divided by the fisherman's biological response. The fisherman's biological response must be included since the tax influences catches through the stock effect.

Note that the tax structure eliminates free riding. From (10), it is seen that the fishermen pay on the basis of the full marginal costs that illegal landings generate (the difference in user costs). In this way, free riding is eliminated and compliance with the total quota is ensured—the incentive for illegal landings is avoided. This result is analogous to the result in Segerson (1988).

It is useful to differentiate the tax function in order to highlight how changes in x_{t+1}, x_t and h_{it} influence the variable tax rate. In order to do this an assumption is necessary. It is assumed that the sign of the partial derivative of Q with respect to a variable is the same as the sign of the partial derivative of the social user cost with respect to the same variable. The explanation for this assumption is that $\sum_{j\neq i}\partial c_j/\partial x_{t+1}$ enters in the social user cost (the social user cost is higher than the user cost for the fishermen). Because of this assumption $\partial Q/\partial h_{it} < 0$, $\partial Q/\partial x_t > 0$ and $\partial Q/\partial x_{t+1} < 0$. The explanation for the fact that $\partial Q/\partial x_{t+1} < 0$ is the assumption that $\partial^2 c_{it}/\partial x_{t+1}^2 > 0$, while $\partial Q/\partial h_{it} < 0$ because $\partial^2 c_{it}/\partial x_{t+1} h_{it} > 0$. $\partial Q/\partial x_t > 0$ because there is a cost reduction associated with increased catches. In connection with the discussion of $N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})$ it was mentioned that it is assumed that $\partial^2 N_{it}/\partial h_{it}^2 > 0$ and $\partial^2 N_{it}/\partial h_{it}\partial x_t < 0$. All this implies that:

$$\frac{\partial t_{it}}{\partial x_t} = \frac{(\partial Q/\partial x_t)(\partial N_{it}/\partial h_{it}) - Q(\partial^2 N_i/\partial h_{it}\partial x_t)}{(\partial N_i/\partial h_{it})^2} < 0 \tag{11}$$

$$\frac{\partial t_{it}}{\partial x_{t+1}} = \frac{(\partial Q/\partial x_{t+1})(\partial N_{it}/\partial h_{it})}{(\partial N_i/\partial h_{it})^2} > 0 \tag{12}$$

$$\frac{\partial t_{it}}{\partial h_{it}} = \frac{(\partial Q/\partial h_{it})(\partial N_{it}/\partial h_{it}) - Q(\partial^2 N_i/\partial h_{it}^2)}{(\partial N_i/\partial h_{it})^2} > 0 \tag{13}$$

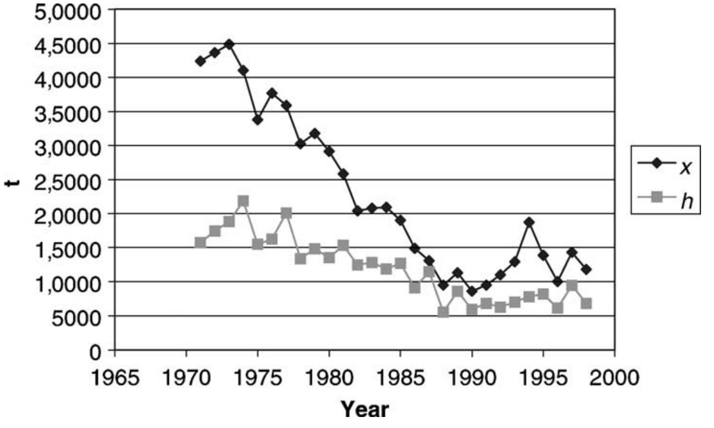

Fig. 2. Development in stock size and aggregated catches.

The explanation for (11) is that if the current stock size increases, h_{it} must also increase and therefore the variable tax must decreases. From (12), it follows that if the target stock size increases, t_{it} must also increase. The explanation for this result is that an increase in the target stock size implies that current catches must decrease. In (13), it is stated that $\partial t_{it}/\partial h_{it} > 0$. The reason for this is that if catches are increased, illegal landings must be decreased.

3. Simulation results

Some simulation results for cod in the Kattegat are now presented. Kattegat is a small sea east of Denmark with a small population of cod. The motivation for the simulations is to obtain a rough indicator for the magnitude of the variable tax rates.[10] Indeed, simulations of mechanism design may, as described in Section 1, throw new light on such mechanisms. First, a description of the cod fishery in Kattegat in given in Fig. 2.

From Fig. 2, it is seen that the stock size and catches decrease from 1971 to 1990. From 1990 onwards the fishery starts to recover. It is also seen that the cod fishery in Kattegat is a small fishery.

[10] In principle, it could also be of interest to calculate total tax costs. This would, however, not be reasonable for the following reasons. With the assumed non-linear cost function, gradual adjustments 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 Jensen and Vestergaard (2000). This yields a carrying capacity of 170,496 t and therefore, $x_{\mathrm{MSY}} = 85,248$ t. Because $\partial c_i/\partial x < 0, G'(x^*) < 0$ and thereby $x^* > 85,248$ t, but the actual stock size is at most 44,856 t. Therefore, the actual tax costs will be seriously overestimated. This conclusion holds for another reason. The procedure in Section 2 was that society announced a tax formula, (1), 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 ensures that x is close to x^*, and in theory $x = x^*$ and total tax revenue for society will be 0. By using actual stock sizes to calculate total tax costs, the effect that announcement of a tax formula would have on x is excluded.

Some assumptions are necessary for the simulations to be conducted. First, full information is assumed. Furthermore, the simulations are conducted for an economic objective and it is assumed that the fishery is always in steady state. This implies that long-run economic yield is maximized and $x_{t+1} = x_t = x$. In other words, society's maximization problem, with h_i as the control variable and x as the state variable, may be written as max $\sum_{i=1}^{n} ph_i - c(x, h_i)$ s.t. $G(x) - \sum_{i=1}^{n} h_i = 0$. The restriction may be solved for x to yield $x = M(h_i, \boldsymbol{h_{-i}})$. Now $M(h_i, \boldsymbol{h_{-i}})$ is an expression for how the steady-state stock size is related to catches and $\partial M/\partial h_i$ is the biological response function. The biological response function indicates how the steady-state stock responds to changes in individual catches. In optimum, it will be the case that $\partial M/\partial h_i < 0$. $M(h_i, \boldsymbol{h_{-i}}.)$ may be substituted into the objective function and the first-order condition for fisherman i states that $p - \partial c_i/\partial h_i - \partial c_i/\partial M\, \partial M/\partial h_i - \sum_{j \neq i} \partial c_j/\partial M\, \partial M/\partial h_i = 0$. The expression $\partial c_j/\partial M\, \partial M/\partial h_i + \sum_{j \neq i} \partial c_i/\partial M\, \partial M/\partial h_i$ is the user cost of the fish stock. With respect to fisherman i, h_i is the control variable and the maximization problem is $\max(ph_i - c_i(h_i, x) - T_i(x))$ s.t. $x = N(h_i, \boldsymbol{h_{-i}})$. The first-order condition with Cournot–Nash expectations is $p - \partial c_i/\partial h_i - \partial c_i/\partial N_i\, \partial N_i/\partial h_i + t_i \partial N_i/\partial h_i = 0$.

Now assume that vessels can be collected in homogeneous groups and call n_i the number of vessels in group i. The variable tax formula for an individual vessel in group i can be arrived at by equating the first-order condition for society with the first-order condition for the fisherman. This yields the following tax formula:[11]

$$t_i = \frac{(\partial c_i/\partial N_i)(\partial N_i/\partial h_i) - n_i(\partial c_i/\partial M)(\partial M/\partial h_i) - \sum_{i \neq j} n_j(\partial c_j/\partial M)(\partial M/\partial h_i)}{\partial N_i/\partial h_i} \tag{14}$$

Individual variable tax rates have been calculated for six vessel groups.

- Netters under 20 gross tonnes (GT).
- Netters over 20 GT.
- Danish Seiners.
- Trawlers under 50 GT.
- Trawlers between 50 and 199 GT.
- Trawlers over 200 GT.

The tax rates are for the average vessel within these groups for 1971–1998. More than one group have been selected since an interest is in focusing on the size of the tax difference that eliminates free riding.

It can be concluded that the fishermen face a variable tax, not a variable subsidy, every year. In Jensen and Vestergaard (2000), a logistic growth function is estimated and the carrying capacity is 170,496 t. Now $x_{\text{MSY}} = 85,248$ t and in optimum $G'(x^*) < 0$, so $x^* > 85,248$ t. But in the period 1971–1998, x is at maximum 44,856 t, so $x^* > x$.

[11] In the case of discards of catches of targeted species, the fishermen receive no price for their catches and discards have no social value, because the social welfare function is defined over the resource rents. Now the parameter α is reflected in all the terms in the tax formula, so the tax may also solve discards of catches for targeted species. Therefore, the simulations in this section also apply to moral hazard problems that arise from discards of catches of targeted species.

Table 1
The calibration results

Group	α_i (1000 kr/t)	β_i (1000 kr/t)
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 and 199 GT	233.29	744.623
Trawlers over 200 GT	31.820	4305.97

Some assumptions have been adopted in order to keep the simulations simple. It is assumed that $N_i(h_i, \boldsymbol{h}_{-i}) = s\,M(h_i, \boldsymbol{h}_{-i})$ with $s \leq 1$; $s = 1$ is the case described in Arnason (1990), but $s < 1$ allows for the fishermen to take some notice of the biomass growth constraint. For cod in the Kattegat four cases have been simulated: $s = 1$; $s = 0.8$; $s = 0.6$; $s = 0.4$.

The simulations of individual variable tax rates require knowledge of an individual cost function. The following cost function for cod has been calibrated:

$$c_i(x, h_i) = \alpha_i + \frac{\beta_i h_i^2}{x} \tag{15}$$

The term α_i denotes costs that are independent of harvest, where administrative costs are examples of such costs. Jensen and Vestergaard (2000) contain all the details regarding the calibration including the empirical model for the calibration of the parameters. Table 1 summarises the results.

Now the simulation results for individual variable tax rates can be presented, see Figs. 3–8.

A striking feature is that the variable taxes rates are low compared to the sale price (the sale price is between 8200 and 13,500 DKK/t)—the tax is at maximum 1200 DKK/t (or

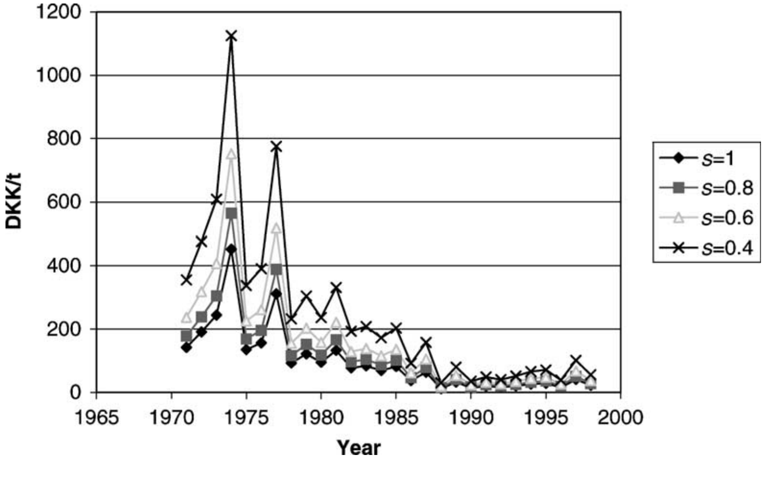

Fig. 3. Individual variable tax rates: netters under 20 GT.

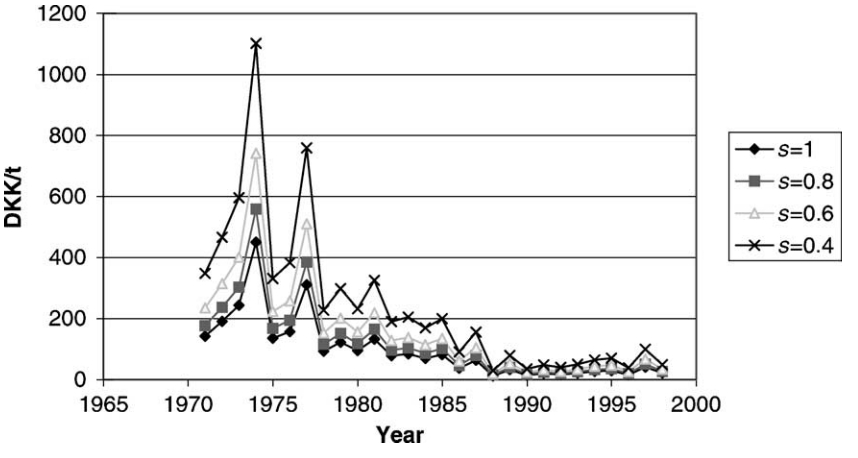

Fig. 4. Individual variable tax rates: netters over 20 GT.

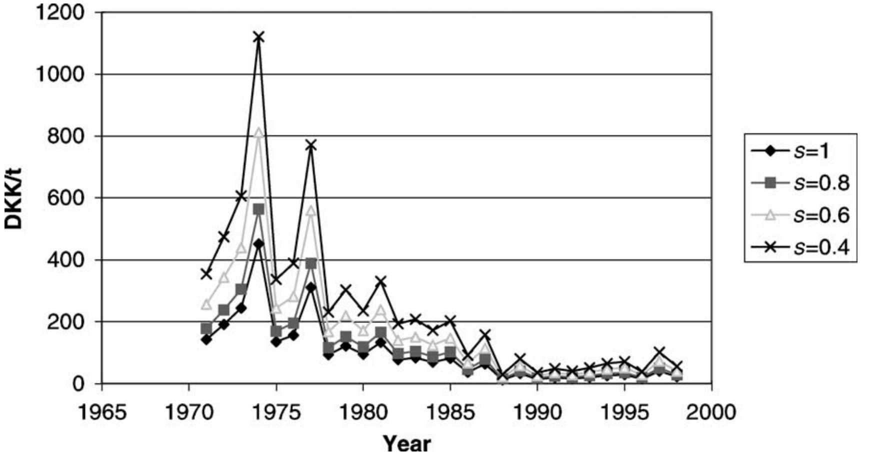

Fig. 5. Individual variable tax rates: Danish Seiners.

10% of the sale price).[12] 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 large, and the variable tax rate must be large. The variation in taxes over time can be explained by variations in h_i and steady-state stock size. By differentiating the tax function, it can be shown that if catches are increased, the variable tax will also increase. Furthermore, if $M(h_i, \boldsymbol{h}_{-i})$ is increased, the variable tax rate will decrease. These facts explain why the variable tax rate varies over time. A striking feature is that the variable tax rates are high in the early years and low in the later years. This is explained by the fact that catches are

[12] As already mentioned calculations of total taxes are meaningless.

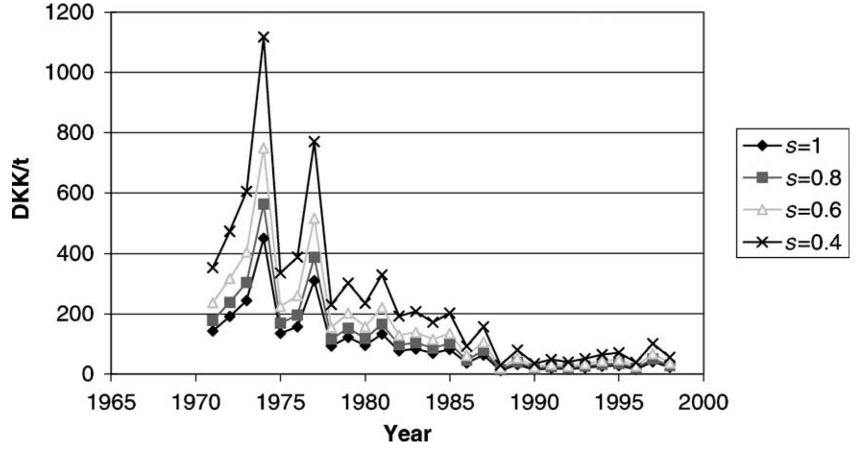

Fig. 6. Individual variable tax rates: trawlers under 50 GT.

high and $M(h_i, \boldsymbol{h}_{-i})$ is low in the early years, while h_i is small and $M(h_i, \boldsymbol{h}_{-i})$ is high in the later years. Note, however, that the proportion a vessel catches of the total catch is fixed at the 1997 level because of the lack of time series data 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.

But how robust to changes in the parameters and functional forms is the conclusion that the variable tax rate is low compared to the sale price? First, a sensitivity analysis with respect to changes in the cost parameter is conducted. Because the variations in tax rates over time can be explained by variations in h_i and x, only results for 1997 are presented.

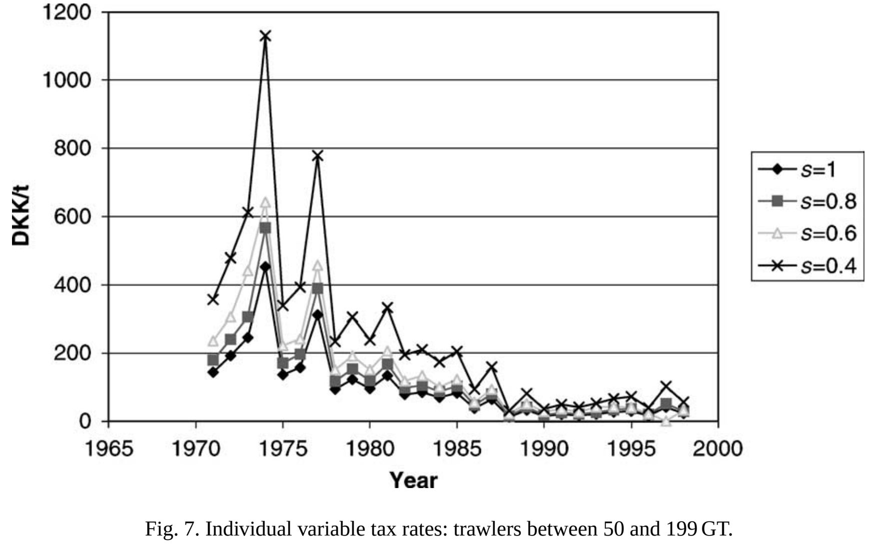

Fig. 7. Individual variable tax rates: trawlers between 50 and 199 GT.

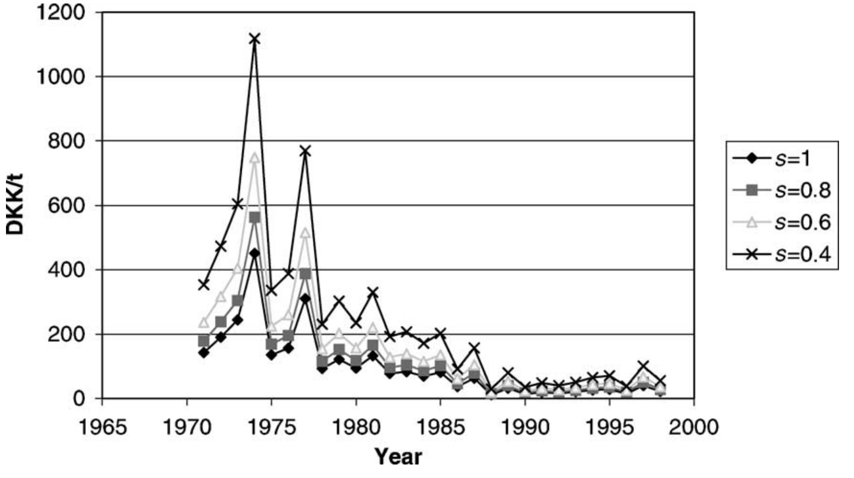

Fig. 8. Individual variable tax rates: Trawlers over 200 GT.

Table 2
Sensitivity analysis of variable tax rates for Danish Seiners, 1997, $s = 0.4$

α_I	t_i
1260	80.88
1576	101.11
1894	121.34

Furthermore, because of lack of variation in variable taxes between vessel groups, only estimates for Danish Seiners are presented. The variable cost estimates for all vessel groups in Table 1 is varied by +/−20% and the results are shown in Table 2.

With a sale price of 11,200 DKK/t, the conclusion is that the variable tax rate constitutes a low share of the sale price, is not sensitive to changes in the parameters. This conclusion holds irrespectively of the choice of year and vessel group.

But how sensitive is this conclusion to alternative functional forms for the cost function? In order to highlight this, two alternative cost functions have been calibrated:[13]

$$C_i(h_i, x) = \alpha_i + \frac{\beta_i h_i^2}{\sqrt{x}} \text{ (formulation 2)} \tag{16}$$

$$C_i(h_i, x) = \alpha_i + \frac{\beta_i h_i}{x} \text{ (formulation 3)} \tag{17}$$

In the second formulation, the square root of x is taken instead of x and the third formulation amounts to assuming that the cost function is linear in catches. The marginal taxes that result from these formulations are described in Table 3 for $s = 0.4$, Danish Seiners and 1997.

That t_i is larger in formulation 2 is not surprising. With the square root of x instead of x, $\partial c_i/\partial M$ becomes larger, and even though calibrations show that β_i becomes smaller,

[13] With regard to details on the calibration of these cost functions, see Jensen (in press).

Table 3
Sensitivity analysis of alternative functional forms, Danish Seiners, 1997, $s = 0.4$

Formulation	t_i
1	101.1
2	164.63
3	201.19

the first effect dominates the second effect. An opposite conclusion applies to the third formulation. Even though $\partial c_i/\partial M$ is smaller, this effect is dominated by the fact that β_i is larger. Even though Table 3 shows that there are variations in the marginal taxes with the functional forms, these variations are very small compared to the sale price (between 1 and 2%). Note also that the original formulation corresponds to a case where the calibration of the cost function is done without costs that are independent of harvest. The reason for this is that the calibrated variable cost will be the same with and without α_i. Furthermore, only the variable cost enters into the tax formula.

To sum up, the incentive scheme has potential applications 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 have traditionally been seen as impossible within fisheries. Clark (1990) proposes a combination of a tax system and a system of ITQs to secure a fair distribution 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. Furthermore, it can be argued that the tax arrived at in this paper is no different from a traditional output tax. A traditional output tax with economic objectives is equal to the user costs of the fish stock, as, in principle, is the tax in this paper.[14] However, with regard to output taxes, an important difference arises. In this paper, it is stock size, not harvest, that is the tax variable.

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 solve 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-balance problem is to pay back the social benefit from falling in line with the optimal catches to the industry. In this manner, budget-balance can be achieved.

[14] Important articles on output taxes include Androkovich and Stollery (1991) and Weitzman (2000).

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 (1991) and Govinsdasamy et al. (1994). Within fisheries, economic taxes have traditionally been criticized for posing too many information requirements, see Arnason (1990). The information requirements mentioned by Arnason (1990) can be seen from the model in Section 2, because the user cost enters the tax formula and the user cost varies over time. However, 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, in practice the information demands are 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 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 noted that the regulatory structure within the EU fisheries is at least as complex, see Jensen and Vestergaard (1999) and Holden (1996). Another information problem that arises is that the tax mechanism is unworkable without reliable cost data.[15] Therefore, cost data must be collected, but for many fisheries, such data are not collected at the present time. However, this also represents a challenge to authorities, because any attempt to regulate in an optimal fashion depends on reliable cost data. For example, in setting optimal individual quotas, society is also dependent on reliable cost data. A question that arises is how reliable cost data could be collected if the fishermen knew they were used to calculate a stock tax. A solution to this problem could be to collect the data by participating on random fishing trips.

The discussion of information problems are related to the analysis by Cabe and Herriges (1992), who mention two points in connection with non-point pollution. First, the Segerson tax mechanism will only work if producers perceive they have a significant influence on the ambient concentration at the damage site. For the model in this paper, this means that fishermen must react to the stock tax by taking some account of 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. Note, however, that the tax will work if a biological criteria is used to determine the quota. All that is required is that the marginal value of individual catches is determined. Second, the analysis by Segerson assumes that monitoring the aggregated pollution level is costless. This problem is related to the problem of obtaining a reliable measure for stock size. Even though catches are made observable by use of a stock tax, measurement problems still remain. However, for many developed fisheries, stock estimates are already collected

[15] Weitzman (1974), Anderson (1986) and Androkovich and Stollery (1991) have worked with harvest taxes in the light of uncertainty about the cost function. However, in the case of stock taxes, a necessary condition is to obtain a precise measure of the cost function.

for other purposes so it is costless to obtain a stock size measure. Despite these points this paper does not attempt to solve the problems mentioned by Cabe and Herriges (1992), but it could be argued that these problems are not as significant within fisheries as within non-point pollution, because it was possible to simulate the variable tax rates in Section 3.

5. Conclusion

In this paper, an economic incentive scheme is presented as a solution to problems associated with illegal landings and discards. 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. The world wide response to problems of illegal landings and discards has been to use such policies but these are is expensive to administer. Indeed, the extreme case of on-board observations very costly.

Since there are problems associated with illegal landings and discards, 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. If the actual fish stock is above the optimal stock, fisherman i receives 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. By the right selection of the individual tax/subsidy rate, optimal individual catches can be achieved. 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 of the tax/subsidy. Therefore, compliance with the total quota is reached. Simulations for cod fishing in the Kattegat reveal a striking result. The variable tax rates are in some cases only 1% of the sale price. Note, however, that the results of the simulations are very rough estimates of the actual tax rates.

Three assumptions are worth repeating. First, the analysis is based on a single species assumption. In a multi-species setting the marginal taxes is expected to depend on the technical interaction present in the production technology. However, if non-joint production is assumed the results in this paper generalize to a multi-species situation. Second, the mechanism assumes that the stock size and costs are observable. A problem with the proposed tax mechanism is to get reliable measures for the fish stock and costs. However, this problem may be seen as a challenge to society and also arises with other attempts to regulate. Third, 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 Section 1, it was pointed out that discards also pose problems with compliance to total quotas. The tax mechanism can also solve this problem.

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