Fisheries Management with Multiple Market Failures

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Abstract

Within fisheries it is well-known that several market failures exist. However, fisheries economists analyse these market failures separately despite the fact that the market failures arise simultaneously. In this paper several market failures that arise simultaneously are analysed. A resource stock tax and a tax on self-reported harvest are considered as a solution to problems associated with the stock externality, measuring individual catches and stock uncertainty. Within a fisheries economic model it is shown that it will be in the interest of risk-averse fishermen to report a part of their catch even without a control policy. In addition, it is shown that this tax structure can secure optimal expected individual catches and simulations show that the tax payment is very low. Thus, the tax system may be useful in practical fisheries management.

Key words: Prices regulation, Quantity regulation, Asymmetric Information, Self-Reporting, Stock Tax and Harvest Tax.

JEL Classification: Q22, K4, L51.

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1. Introduction

Property rights have become the conventional wisdom for the best way to manage fishing industries. This debate, once thought closed, has recently been reopened. Weitzman (2002) argues that harvest taxes are preferred over individual transferable quotas (ITQs) under uncertainty about the biological relation (environmental uncertainty), because it is possible to reach the desired escapement level of recruits with taxes. Jensen and Vestergaard (2003) argue that in a schooling fishery where there is imperfect information about the cost function (economic uncertainty), taxes may be preferred over ITQs if the marginal cost function is steeper than the marginal benefit function. Thus, these two articles present arguments for taxes under environmental and economic uncertainty.

A tax system is also analysed in Jensen and Vestergaard (2002). The point of departure for Jensen and Vestergaard (2002) is that within fisheries a moral hazard problem arises because individual catches is unobservable. For example, an ITQ system creates incentives to exceed the quota because problems with illegal landings and discard arise. Thus, Jensen and Vestergaard (2002) analyse economic uncertainty and, in addition to solve this uncertainty, the mechanism proposed also solves the stock externality problem. In this paper the analysis in Jensen and Vestergaard (2002) and Weitzman (2002) is generalised. The paper analyses an incentive scheme that can be applied both in the presence of both environmental uncertainty (stock uncertainty) and economic uncertainty (imperfect information about harvest).

When imperfect information about catches, stock uncertainty and stock externality problems occurs simultaneous three market failures arise. It is a well-known general result within economics that if several market failure problems interacts several policy instruments must be used to secure a first best optimum. Analyses of stock uncertainty and problems with measurement of individual catches have been usually accomplished separately within fisheries economics. The so called stochastic bioeconomics (see Andersen and Sutinen (1984) for an overview) analyse optimal exploitation of the fisheries resource in the light of

stock uncertainty, while, as mentioned above, Jensen and Vestergaard (2002) analyse a stock tax as a solution of problems with imperfect information about catches.

As mentioned above the purpose of this paper is to combine a stock tax and a tax on self-reported catches to solve the stock externality problem, the problem of imperfect information about catches and the stock uncertainty problem.[1] In the fisheries economic literature no attempt has, to our knowledge, been made to solve several market failures simultaneously and, therefore, this paper is a novel contribution to this literature. As mentioned above the mechanism proposed in this paper combines a resource stock tax and a tax on self-reported harvest to solve several market failures that arises simultaneously. Thereby, it is implicitly argued that taxes are preferred over individual quotas when several market failures arise because an ITQ system only is designed to solve the stock externality problem.

The result that several market failures can be corrected by the use of several instruments generalise to other common pool resources. For example, a private owned forest should be harvested such that the present value of net benefits is maximised. At least two market failures arise in the case of private owned forests. First, there can be a difference between the private and social discount rate. Second, poverty and debt in the developing countries can lead to overharvesting of forests. A combination between public ownership and international agreements that may involve subsidies from the developed to the undeveloped countries may solve these problems.

1 The idea to the paper is taken from the work by Xepapadeas (1995) on non-point pollution. However, three important differences arise from Xepapadeas (1995). First, Xepapadeas (1995) uses a static model, while the model in this paper is dynamic. Second, the tax structure is simulated in this paper in order to obtain a rough indicator for the size of the tax payment. Third, Xepapadeas (1995) makes use of monitoring effort in order to secure self reported harvest. In this paper it is shown that reporting part of the catches is optimal even without monitoring effort.

The use of incentive schemes based on self-reported harvest to design optimal management of fisheries is also a novel thought within the fisheries economic literature. A common procedure when managing fisheries is that vessel skippers shall keep a logbook to record the quantity of each species caught. The bodies responsible for the first marketing shall submit a sales note containing information on the quantity of all species landed. Now an important aspect of fisheries management is a control policy where cross checking of sales notes and logbooks occurs. However, such a control policy is costly and for this reason it is important to construct incentive mechanisms that solve the problem with unobservable individual catches. Such a mechanism is constructed in this paper, where self-reporting of catches occurs irrespectively of a control policy if fishermen is risk averse with respect to the stock tax payment. In Hansen *et al.* (2003) a mechanism that secures truthful revelation of catches *ex ante* is constructed. However, the approach taken in this paper is different from the approach in Hansen *et* al (2003) because the interest is not in truthful revelation. Instead the tax on self-reported harvest is based on the *ex post* chosen report by the fisherman in this paper.

The paper is organised as follows. In section 2 the model is presented, while section 3 analyses optimal self-reporting by fishermen under stock certainty. Section 4 examines stock uncertainty, while some simulations are presented in section 5. Some discussion points and a conclusion regarding the suggested tax mechanism are presented in section 6.

2. The model

Consider a fishery consisting of n fishermen where a central authority (society) imposes a total quota on the industry. Individual catches are assumed to be unobservable to society. Each year, t, society calculates a target stock size for the end of the year, x_{t+1}*. On basis of this target year-end stock size, society calculates the optimal aggregated catches, h_t*. The optimal target year-end stock size and the optimal aggregated catches can now be announced.

This set up is similar to the model in Jensen and Vestergaard (2002). However, in this paper there is an important difference compared to Jensen and Vestergaard (2002). Jensen and Vestergaard (2002) assume that stock size can be measured exactly, and therefore a stock tax is studied as a solution to problems with imperfect information about catches. In reality, there are measurement problems associated with obtaining a reliable measure for stock size, see Anon (2002). Therefore, stock size is assumed to be a stochastic variable in this paper. Hence, two market failures (apart from the stock externality problem) are analysed in this paper, imperfect information about individual catches and uncertainty about stock size, and these two market failures interact. When two market failures interact, it is in general necessary to use two policy instruments to correct these market failures. Based on Xepapadeas (1995), the following instruments are analysed in this paper:

a. A harvest tax rate, τ_{it}, per unit of individual, self-reported catches, s_{it}, in the period between t and $t+1$. It is assumed that $\tau_{it} > 0$.

b. A stock tax based on the difference between the target year-end stock size and the actual stock size at the end of the year, x_{t+1}. The stock tax function is specified as a function of the self-reported catches of fisherman i, $g_{it}(s_{it})$. The time period between t and $t+1$ is the same for the stock tax function and the self-reporting tax rate. It is assumed that $g_{it}'(s_{it}) < 0$ and $g_{it}''(s_{it}) < 0$. It is also assumed that there is a relation between the levels of self-reported catches and real catches for fisherman i. This relation is specified as $s_{it} = f_{it}(h_{it})$, where $f_{it}'(h_{it}) > 0$ and $f_{it}''(s_{it}) > 0$. By use of $f_{it}(h_{it})$ the stock tax function may be written as $g_{it}(s_{it}) = g_{it}(f_{it}(h_{it})) = k_{it}(h_{it})$, where k_{it} is the stock tax as a function of harvest. The assumptions about $g_{it}(s_{it})$ and $f_{it}(h_{it})$ imply that $k_{it}'(h_{it}) < 0$ and $k_{it}''(h_{it}) < 0$.

A further assumption is that there is no control policy and, therefore, the fisherman can exceed the total quota by any amount that is optimal. Instead of a control policy, a resource stock tax and a tax on self-reported harvest is imposed and analysed as an alternative to a control policy in this paper. Further-

more, it is assumed that the fisherman receives the same price for all landings and a single-species assumption is adopted. A normal assumption in fisheries economics is that each individual fisherman disregards resource conservation measures corresponding to the stock externality problem; see Clark (1990). However, as pointed out by Jensen and Vestergaard (2002), this assumption is not reasonable in the presence of a stock tax. According to Jensen and Vestergaard (2002), the following function is, therefore, included as a restriction on the maximisation problem for fisherman *i*:

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

where h_{it} is the catch of fisherman *i* in the period between *t* and *t+1* and h_{-it} is a vector of catches for all other fishermen in the same period. $N_{it}(x_t, h_{it}, h_{-it})$ is an expression for how fisherman *i* perceives that the stock size at time *t+1* is influenced by catches and it is assumed that $\partial N_{it}/\partial h_{it} < 0$. Furthermore, it is assumed that $\partial^2 N_{it} / \partial h_{it}^2 > 0, \partial^2 N_{it} / \partial h_{it} \partial x_t < 0$ *and* $\partial^2 N_{it} / \partial h_{it} \partial x_{t+1} > 0$. $N_{it}(x_t, h_{it}, h_{-it})$ may differ from the true resource restriction in societies maximisation problem. As explained by Jensen and Vestergaard (2002) individual fishermen may have wrong perceptions regarding how harvest influence the stock size. Arnason (1990) builds a model where fishermen include the true resource restriction in their maximisation problem. Thus, the analysis in this paper is more general than the analysis in Arnason (1990) because the possibility of wrong perceptions by the fisherman is included.

The individual fisherman maximise the profit minus the tax payment in each time period and, therefore, the maximisation problem of fisherman *i* may be written as:

$$\underset{h_{it}, f_{it}}{Max}\left(ph_{it} - c_{it}(x_t, x_{t+1} - x_t, h_{it}) - k_{it}(h_{it})(x^*_{t+1} - x_{t+1}) - \tau_{it} f_{it}(h_{it}) \right) \tag{2}$$

s.t.

$$x_{t+1} = N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) \tag{3}$$

where p is the output price and $c_{it}(x_t, x_{t+1} - x_t, h_{it})$ is the cost function. It is assumed that $\partial c_{it}/\partial x_t < 0$, $\partial c_{it}/\partial h_{it} > 0$ $\partial^2 c_{it} / \partial h_{it}^2 > 0, \partial^2 c_{it} / \partial x_t^2 > 0$ *and* $\partial^2 c_{it} / \partial h_{it} \partial x_t > 0$.[2] The maximisation in (2) occurs with respect to the harvest (h_{it}) and self-reported catches (s_{it}). However, because there is a relation between the level of the self-reported harvest and the catches ($s_{it} = f_{it}(h_{it})$), maximisation with respect to self reported harvest is the same as maximising with respect to $f_{it}(s_{it})$. Maximisation of a function is well-known within economics, see Varian (1992). In (2) ph_{it} is the revenue, $c_{it}(x_t, x_{t+1} - x_t, h_{it})$ is the production costs and $k_{it}(h_{it})(x_{t+1}^* - x_{t+1}) + \tau_{it} f_{it}(h_{it})$ is the tax payment.

Substituting (3) into (2) yields the following profit function for fisherman *i*:

$$\underset{h_{it}, f_{it}}{Max}\left(ph_{it} - c_{it}(x_t, N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) - x_t, h_{it}) - k_{it}(h_{it})(x^*_{t+1} - N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})) - \tau_{it} f_{it}(h_{it}) \right) \tag{4}$$

With regard to society, a stochastic version of a management model in Clark (1990) is adopted to analyse the welfare optimisation problem. Society maximises the expected value of future resource rents from $t = 0, \ldots\ldots, \infty$. Therefore, according to Clark (1990) the maximisation problem of society may be written as:

$$\underset{h_{it}, k_{it}}{MaxE}\left(\sum_{i=1}^{n} \sum_{t=0}^{\infty} ph_{it} - c_{it}(h_{it}, x_t, x_{t+1} - x_t)\rho^t \right) \tag{5}$$

s.t

2 Note that the development in stock size for the period between *t* and *t+1* is included in the cost function. This assumption can be deduced from the model in Clark (1990) for total quotas, where the integral of the objective function is defined for *t=0* to the time when the quota is filled. The explanation for this assumption is that changes in stock size between discrete time periods will influence cost of harvesting fish.

$$F(x_t) - E(\sum_{i=1}^{n} h_{it}) + x_t = x_{t+1} \tag{6}$$

$$\begin{aligned} &h_{it}, f_{it} \ \varepsilon \ arg\,max(ph_{it} - c_{it}(x_t, N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) - x_t, h_{it}) - \\ &k_{it}(h_{it})(x^*_{t+1} - N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})) - \tau_{it} f_{it}(h_{it})) \end{aligned} \tag{7}$$

where $F(x_t)$ is the natural growth rate, $E(.)$ is the expectation operator included because individual catches is unobservable, and ρ is a discount rate. (5) is an expression for the expected present value total resource rent for all fishermen in all time periods. The policy instruments for society is the stock tax function, $k_{it}(h_{it})$, and the harvest tax rate, τ_{it}. (5) capture that these policy instruments shall be fixed such that social optimal individual catches is reached. However, in order to find social optimal catches, the first-order condition with respect to h_{it} must be found. In addition, it is only necessary to find the first-order condition with respect to $k_{it}(h_{it})$ because by using the first-order of the fisherman with respect to the self reported harvest, the optimal τ_i may be found. Therefore, (5) is maximised with respect to h_{it} and $k_{it}(h_{it})$. In (6) $x_{t+1} - x_t$ is the change in stock size between t and $t+1$ and (6) captures that the change in stock size must equal the natural growth rate minus harvest. This equation is known as the resource restriction. (7) captures that in selecting h_{it} and k_{it}, society must accept the choice of the fishermen of catches and self reported harvest. By assuming interior solutions for f_{it} and h_{it} (s_{it}, $h_{it} > 0$) (7) can be replaced by the first-order conditions. With this procedure the maximisation problem may be solved with the Lagrange-method.

An important difference between the social and the private (fishermen) optimum can be is seen from comparing (7) and (5). The fishermen maximises profit in each period while society selects a profile of optimal harvest for each time period at $t=0$. In other words, fishermen do not take into account the interaction that arises between time periods in exploitation of a renewable resource like fish.

Before the maximisation problem is solved, it is useful to substitute (6) into the objective function and, therefore, the maximisation problem of society may be written as:

$$\underset{h_{it},k_{it}(}{MaxE}(\sum_{i=1}^{n}\sum_{t=0}^{\infty} ph_{it} - c_{it}(h_{it}, x_t, F(x_t) - \sum_{i=1}^{n} h_{it})\rho^t) \tag{8}$$

s.t.

$$h_{it}, f_{it}\ \varepsilon\ arg\,max(\ ph_{it} - c_{it}(x_t, N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}) - x_t, h_{it}) - k_{it}(h_{it})(x^*_{t+1} - N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it})) - \tau_{it} f_{it}(h_{it})) \tag{9}$$

Again (8) is an expression for the present value of resource rents of all fishermen in all time periods. By solving (8) subject to (9), the optimal values of catches, h_{it}*, the self-report tax rate, τ_{it}*, and the stock tax function, k_{it}*(h_{it}), can be found.

3. Full certainty

In this section it is shown that with full stock certainty it is optimal for fisherman *i* to report zero catches. In addition, the optimal stock tax function is calculated. The first-order condition of the maximisation problem for fisherman *i* with respect to f_{it} for the period *t* is:

$$k_{it}'(h_{it})(x_{t+1}^* - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t)) - \tau_{it} \le 0, f_{it} \ge 0 \tag{10}$$

In (10) $k_{it}'(h_{it})$ is included because $k_{it}(h_{it})$ can be expressed as $g_{it}(f_{it}(h_{it}))$.

By optimal selection of the stock tax function and self-reporting tax rate it can be secured that $N_{it}(h_{it}, h_{-it}, x_t) = x_{t+1}$*. In addition, it is assumed that $\tau_{it} > 0$ and, therefore, (10) can be reduced to:

$$-\tau_{it} < 0, f_{it} = 0 \tag{11}$$

From (11) it is seen that it is optimal for vessels not to reveal any information about their catches. The explanation for this result is that without stock uncertainty, the fisherman is indifferent between paying the stock tax and the harvest tax. Thus, the fisherman might as well declare $f_{it} = 0$ and, thereby, avoid the self-reporting tax payment.

The first-order condition of the maximisation problem of fisherman i ((4)) with respect to h_{it} in period t, noticing that $x_{t+1}^* = N_{it}(h_{it}, \mathbf{h}_{-it}, x_t)$, is:

$$p - \frac{\partial c_{it}}{\partial N_{it}} \frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial h_{it}} + k_{it}(h_{it}) \frac{\partial N_{it}}{\partial h_{it}} = 0 \tag{12}$$

(12) states that the marginal benefits (p) equals the marginal private costs. The marginal private costs consists of the marginal production costs ($\partial c_{it}/\partial h_{it}$), the marginal stock tax costs ($k_{it}(h_{it})\ \partial N_{it}/\partial h_{it}$) and the marginal user costs of the fish stock as perceived by the fisherman ($\partial c_{it}/\partial N_{it}\ \partial N_{it}/\partial h_{it}$).

As mentioned in section 2, (9) can be replaced by (12) in societies maximisation problem, if an interior solution for h_{it} exists. Furthermore, it is not necessary to take into account the first-order condition for f_{it}, because $f_{it} = 0$ in optimum. Therefore, the following present value Lagrange function can be set up for society:

$$\begin{aligned} &\underset{h_{it}, k_{it}}{MaxL} = E\Big(\sum_{i=1}^{n} p h_{it} - c_{it}(h_{it}, x_t, F(x_t) - \sum_{i=1}^{n} h_{it}) + \\ &\sum_{i=1}^{n} \lambda_{it} \Big(p - \frac{\partial c_{it}}{\partial N_{it}} \frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial h_{it}} + k_{it}(h_{it}) \frac{\partial N_{it}}{\partial h_{it}}\Big) \end{aligned} \tag{13}$$

Noticing that $\partial x_{t+1}/\partial E(h_{it}) = 1$, the first-order conditions of the Lagrange-function for fisherman i in period t is:

$$\frac{\partial L}{\partial h_{it}} = p - E(\frac{\partial c_{it}}{\partial h_{it}} + \sum_{i=1}^{n} \frac{\partial c_{it}}{\partial x_{t+1}}) - \lambda_{it}(\frac{\partial^2 c_{it}}{\partial h_{it}^2} + \frac{\partial^2 c_{it}}{\partial N_{it}^2}\frac{\partial N_{it}}{\partial h_{it}} + \frac{\partial c_{it}}{\partial N_{it}}\frac{\partial^2 N_{it}}{\partial h_{it}^2} - k_{it}(h_{it})\frac{\partial^2 N_{it}}{\partial h_{it}^2}) = 0 \quad (14)$$

$$\frac{\partial L}{\partial k_{it}} = \lambda_{it}\frac{\partial N_{it}}{\partial h_{it}} = 0 \quad (15)$$

$$\frac{\partial L}{\partial \lambda} = p - \frac{\partial c_{it}}{\partial N_{it}}\frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial h_{it}} + k_{it}(h_{it})\frac{\partial N_{it}}{\partial h_{it}} = 0 \quad (16)$$

From (15) it follows that $\lambda_t = 0$ because $\partial N_{it}/\partial h_{it} < 0$. Therefore, (14) reduces to:

$$p - E(\frac{\partial c_{it}}{\partial h_{it}} + \sum_{i=1}^{n} \frac{\partial c_{it}}{\partial x_{t+1}}) = 0 \quad (17)$$

(17) expresses that the marginal social benefit (p) shall equal the expected marginal social costs. The expected marginal social costs consists of the expected marginal user costs ($\sum \partial c_{it}/\partial x_{t+1}$) and the expected marginal production costs ($\partial c_{it}/\partial h_{it}$). Setting (17) equal to (16), the following stock tax is arrived at:

$$k_{it} = \frac{Q}{\frac{\partial N_{it}}{\partial h_{it}}} \quad (18)$$

where $Q = \partial c_{it}/\partial h_{it} + \partial c_{it}/\partial N_{it}\ \partial N_{it}/\partial h_{it} - E(\partial c_{it}/\partial h_{it})\ - \sum E(\partial c_{it}/\partial x_{t+1})$ is the marginal social costs of optimal catches. Q reflects the difference in user costs between society and the fisherman ($\partial c_{it}/\partial N_{it}\ \partial N_{it}/\partial h_i$ is the expected private user costs while $\sum E(\partial c_{it}/\partial x_{t+1})$ is the marginal social user cost). When the fisherman has correct perceptions regarding the resource restriction and society has correct

expectations regarding the harvest of the fisherman, $Q = \sum_{j \neq i} \partial c_{jt} / x_{t+1}$. In this case the stock tax function is the user cost of the fish stock for society. The user cost captures that each individual fisherman does not take into account the effect that harvest has on other fishermen. This is usually referred to as the stock externality in fisheries economics.

(18) is exactly the stock tax arrived at in Jensen and Vestergaard (2002). The tax arrived at in (18) uses the fish stock as tax base. Normally, harvest is the tax base but we have shown that self-reported harvest is zero and, in addition, catches are not observable. For these reasons, harvest cannot be the tax base in this paper. The stock tax proposed in (18) secures optimal individual catches because the fishermen pay the full social costs that illegal landings generates (the difference in user cost of the fish stock). Therefore, the stock tax can be seen as an argument for using taxes instead of ITQs to manage fisheries because taxes can solve the problem of measuring individual catches. From (18) it is clear that it enough for society to fix the stock tax function when there is stock certainty if the purpose is to secure optimal individual catches. The reason for this result is, naturally enough, that $f_{it} = 0$.

4. Uncertainty

The conclusions in the previous section depend on the assumption that stock size is known with certainty. In reality, this assumption is not very realistic because there is considerable error associated with measuring stock size; see Anon (2002). Therefore, the case of stochastic stock size is now analysed. Stock size is, due to measurement problems, assumed to be a stochastic variable so that $x_t = \bar{x}_t + \varepsilon_t$, where ε_t is a random variable. It is assumed that $E(x_t) = \bar{x}_t, E(\varepsilon) = 0 \text{ and } \sigma_{\varepsilon_t}^{\ 2} = E(\varepsilon_t^{\ 2})$, where $\sigma_{\varepsilon_t}^{\ 2}$ is the variance. Now the perceived biological reaction function for the fisherman may be expressed as $N_{it}(h_{it}, h_{-it}, x_t, \sigma_{\varepsilon_t}^{\ 2})$. The expected social optimal stock size is called x_{t+1}*. An assumption regarding the risk attitude of the individual fisherman now is necessary and it is

assumed that fishermen are risk-averters with respect to stock size. Because fishermen is risk averters with respect to stock size the following function can be formulated with respect to derivations of optimal stock size from actual stock size:

$$\phi_{it}(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) \tag{19}$$

It is assumed that $\phi_{it}(0) = 0$, ϕ_{it}', $\phi_{it}'' > 0$ and $\phi_{it}''' \geq 0$. These assumptions reflect the risk- aversion of the fisherman with respect to stock size. However, (19) is too general to give any quantitative expressions for the self-report tax rate and the stock tax function. Therefore, ϕ_{it} is expressed as a second-order approximation around the point where $x^*_{t+1} = N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)$. With this second-order approximation, (19) may be expressed as:

$$\begin{aligned}\phi_{it}(0) = \phi_{it}(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) + \varepsilon_t \phi_{it}'(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) + \\ \frac{\varepsilon_t^2}{2}\phi_{it}''(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2))\end{aligned} \tag{20}$$

Because $E(\varepsilon_t) = 0$ and $\sigma_{\varepsilon_t}^2 = E(\varepsilon_t^2)$, (20) may be reduced to:

$$\phi_{it}(0) = \phi_{it}(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) + \frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) \tag{21}$$

(21) is the expression for the risk aversion function with respect to the deviation between the optimal and actual stock size that is used in this paper.

Fisherman i is assumed to maximise the expected profit in period t. Because ϕ_{it} captures the risk aversion of an individual fisherman with respect to stock size, (21) can be substituted into (4). This yields the following expected profit function, which shall be maximised with respect to f_{it} and h_{it}:

$$\underset{h_{it},f_{it}}{Max}(ph_{it} - c_{it}(x_t, N_{it}(x_t, h_{it}, \boldsymbol{h}_{-it}, \varepsilon_t) - x_t, h_{it}) - k_{it}(h_{it}) \\ (\phi_{it}(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2)) + \frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(x^*_{t+1} - N_{it}(h_{it}, \boldsymbol{h}_{-it}, x_t, \sigma_{\varepsilon_t}^2))) - \tau_{it} f_{it}(h_{it})) \quad (22)$$

The first-order condition with respect to f_{it} using that if $f_{it}(h_{it})$ and τ_{it} is set correct, $x^*_{t+1} = N_{it}(h_{it}, h_{-it}, x_t, \sigma_{\varepsilon_t}^2)$, is:

$$-k_{it}'(h_{it})(\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0)) - \tau_{it} \le 0, f_{it} \ge 0 \quad (23)$$

Because $k_{it}'(h_{it}) < 0$, $\tau_{it} > 0$ and $\phi'' > 0$, it will be the case that:

$$-k_{it}'(h_{it})(\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0)) - \tau_{it} = 0, f_{it} > 0 \quad (24)$$

(24) states that the expected marginal benefit of self-report expressed as marginal cost savings in the stock tax payment $(-k_{it}'(h_{it})(\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0)))$ shall equal the marginal harvest tax payment (τ_{it}). From (24) it is clear that it is optimal for fisherman *i* to report a part of the catches even if there is no control policy. In other words, the skipper of the vessel will be willing to adjust the harvest so that an expected social optimum is achieved and at the same time pay a tax based on the self-reported part of the catches. In this way, the vessel reduces its stock tax payment if random effects cause $x_{t+1} < x^*_{t+1}$. Xepapadeas (1995) reaches a similar conclusion but for different reasons. In Xepapadaes (1995) polluters are also willing to report part of their pollution but this result arises because society exercises monitoring effort. In this paper, the fishermen self-report a part of the harvest even if there is no control policy. The explanation for this is that the fishermen prefer a certain self-report tax payment over the uncertain stock tax payment if they are risk averse. Thus, risk aversion in itself secures that self-reporting of a part of the catches is optimal.

Note that if the fisherman is risk neutral ($\phi_{it}'' = 0$), they would be indifferent between the stock tax payment and the harvest tax payment. The result that $f_{it} > 0$ is, therefore, driven by the risk-aversion of each individual fisherman. From (24), it is also seen that if the measurement error in stock size is large ($\sigma_{\varepsilon_t}^2$ is large), the self-reported catches will be large, because the first term in (24) increases. The reason for this result is that if the measurement error is large, risk-averse fishermen will do more to avoid the uncertain stock tax payment.

Because $f_{it} > 0$, (24) represents an interior solution and, therefore, (24) is a restriction on the maximisation problem for society. Assuming that an interior solution for h_{it} also exists, this first-order condition is also a restriction on the maximisation problem and from (22) this condition may, noting that $\phi_{it}(0) = 0$, be expressed as:

$$p - \frac{\partial c_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial N_{it}}\frac{\partial N_{it}}{\partial h_{it}} - k_{it}(h_{it})(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}})) = 0 \qquad (25)$$

(25) states that the marginal revenue shall equal the expected marginal private cost for fisherman i. The expected marginal private cost consists of the expected marginal harvest cost, the expected marginal user cost as perceived by the fisherman and the expected marginal stock tax payment.

Using (25) and (24), the following present value Lagrange-function can be set up for society:

$$MaxL = E(\sum_{i=1}^{n} ph_{it} - c_{it}(h_{it}, x_t, F(x_t) - \sum_{i=1}^{n} h_{it}) +$$

$$h_{it}, k_{it}$$

$$\sum_{i=1}^{n} \lambda_{it}(p - \frac{\partial c_{it}}{\partial N_{it}} \frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial h_{it}} + k_{it}(h_{it})\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))) + \quad (26)$$

$$\sum_{i=1}^{n} \mu_{it}(k_{it}'(h_{it})(\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0)) + \tau_{it})$$

The first-order conditions for fisherman *i* in period *t* is:

$$\frac{\partial L}{\partial h_{it}} = p - E(\frac{\partial c_{it}}{\partial h_{it}} + \sum_{i=1}^{n} \frac{\partial c_{it}}{\partial x_{t+1}}) - \lambda_{it}(\frac{\partial^2 c_{it}}{\partial h_{it}^2} + \frac{\partial^2 c_{it}}{\partial N_{it}^2} \frac{\partial N_{it}}{\partial h_{it}} + \frac{\partial c_{it}}{\partial N_{it}} \frac{\partial^2 N_{it}}{\partial h_{it}^2} -$$

$$k_{it}(h_{it})\phi_{it}''(\frac{\partial^2 N_{it}}{\partial h_{it}^2})) = 0 \quad (27)$$

$$\frac{\partial L}{\partial k_{it}} = \lambda_{it}(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}})) = 0 \quad (28)$$

$$\frac{\partial L}{\partial \lambda_{it}} = p - \frac{\partial c_{it}}{\partial N_{it}} \frac{\partial N_{it}}{\partial h_{it}} - \frac{\partial c_{it}}{\partial h_{it}} + k_{it}(h_{it})\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}})) = 0 \quad (29)$$

$$\frac{\partial L}{\partial \mu_{it}} = k_{it}'(h_{it})(\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0)) + \tau_{it}) = 0 \quad (30)$$

From (28) it is obtained that $\lambda_{it} = 0$ because $\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}) > 0$. In this case (27) reduces to:

$$p - E(\frac{\partial c_{it}}{\partial h_{it}} + \sum_{i=1}^{n} \frac{\partial c_{it}}{\partial x_{t+1}}) = 0 \quad (31)$$

(31) states that the marginal social benefit equals the expected marginal social costs. The expected marginal social cost consists of the expected marginal production costs and the expected marginal user cost as perceived by society.

Combining (31) and (29) yields the following expression for the stock tax function:

$$k_{it}(h_{it}) = \frac{Q}{\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''\frac{\sigma_{\varepsilon_t}^{2}}{2}(\frac{\partial N_{it}}{\partial h_{it}})} \tag{32}$$

where Q is defined in (18) and $\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''\frac{\sigma_{\varepsilon_t}^{2}}{2}(\frac{\partial N_{it}}{\partial h_{it}})$ is the marginal risk aversion. The stock tax is, therefore, the expected marginal social cost of optimal catches shared by the marginal risk aversion. It is natural that Q is corrected by the marginal risk aversion is that there is stock uncertainty.

From (30) the tax rate on self reported harvest may be found as:

$$\tau_{it} = -k_{it}'(h_{it})\frac{\sigma_{\varepsilon_t}^{2}}{2}\phi_{it}''(0) \tag{33}$$

The self-reporting tax rate, thus, consists of three elements: the marginal stock tax function, the variance of the uncertain stock size and the second-order derivative of the risk aversion function. The tax structure represented by (32) and (33) will secure optimal expected individual catches and this paper can, therefore, be seen as an argument for using taxes over ITQs to regulating fisheries because a tax system can solve problems with several market failures.

It is also useful to highlight how changes in various variables and functions influence the stock tax function and self-reporting tax rate. This is done by performing comparative statics and the result of the comparative static analysis is

sketched in table 1. The expressions for the comparative static results can be calculated from (33) and (32) and can be found in appendix A.

Table 1. The signs of the comparative static expressions

	Stock tax rate (k_{it})	Harvest tax rate (τ_{it})
Beginning of the year stock size (x_t)	-	-
End-year stock size(x_{t+1})	+	+
Individual harvest (h_{it})	+	+
Risk aversion function ($\phi_{it}(0)$)	-	+
Variance in measuring stock size (σ_{ε_t})	-	+

From table 1 it is clear that if x_t increases, the stock tax function and the self-reporting tax rate decrease. The explanation for this is that if the stock size increases, optimal catches can be increased and, therefore, the tax payment can be decreased. From the comparative static analysis it is also clear that if the target year-end stock size increases the stock tax function and the self-report tax rate must also be increased (table 1). The reason for this is that optimal catches must be reduced if x_{t+1} shall be increased. In table 1 it is also stated that the stock tax function and the self-reporting tax rate is increased if h_{it} is increased. This is explained by the fact that an increase in catches implies an increase in the information problem that arises due to imperfect information about catches. In addition, it is from table 1 seen that an increase in the total risk aversion function ($\phi_{it}(0)$), implies a decrease in the stock tax function and an increase in the self-reporting tax rate. The explanation for this result is that if the total risk aversion increase, it becomes more attractive for the fishermen to report a larger share of their harvest. From table 1 it is also seen that if the variance increases the stock tax rate decreases and the self-report tax rate increases. This conclusion arises because if the variance increases, the measurement error associated

with the stock increases and, therefore, the fishermen wish to report a larger share of their harvest.

A question that arises is if the tax system proposed in this paper is too complex to be implemented in practical fisheries management. (32) and (33) require knowledge of individual cost functions, individual risk aversion functions and individual response to changes in stock size and this is huge information requirements. However, this information can be collected in surveys and, in addition, other attempts to regulate in an optimal fashion also raise huge information requirements. For example, an ITQ system requires that a dynamic optimization problem is solved and this is a difficult task. If a survey is used a procedure could be to form groups of fishermen with similar characteristics. In addition, proxies for the necessary data can be used. Information about the stochastic properties of the stock can be found in Anon (1998). Then, the stock tax function and the self-reporting tax rate can be calculated and announced to the fishermen before a fishing period is started. After the fishing period is ended the tax payment is calculated and the tax rates and functions are announced for the next period. It can be argued that this system is not more complex that the ration system used in Denmark; see Jensen (2002). In Denmark a ration is allocated to each individual fisherman each year and this ration varies each year because of variations in the EU determined quota. Calculating optimal rations also requires substantial information. Thus, the tax system proposed in this paper is not impossible to implement in practical fisheries management and it is, therefore, important to highlight whether the taxes is unrealistically high and examining this question is the purpose of the next section.

5. Simulations

Some simulations for the cod fishery in Kattegat are now presented. Kattegat is a small sea east of Denmark with a small population of cod. The motivation is to obtain a very rough indicator for the magnitude of the stock tax function and the self-reporting tax rate. Jensen and Vestergaard (2002) estimate a pure stock tax function for cod in Kattegat. A conclusion in Jensen and Vestergaard (2002)

is that the stock tax rate function very low compared to the sales price – maximally 10%. The simulations in this paper extend the empirical analysis in Jensen and Vestergaard (2002), because the focus is on calculating the optimal stock tax functions and harvest tax rates in the presence of uncertainty about the stock.

As in Jensen and Vestergaard (2002) individual tax rates and functions have been calculated for six groups of vessels:

- 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

Some assumptions are necessary for the simulations to be conducted. First, it is necessary to assume full information about catches for society. Second, it is necessary to assume that self reported harvest constitutes a fixed part of the harvest each year. Therefore, the functional relation $s_i = \alpha h_i$ is postulated and α is set to 0.3. Third, it is assumed that the fishery is always in steady-state. This implies that long-run economic yield is maximised and $x_{t+1} = x_t = x$. If the first-order conditions for the fisherman is disregarded, the maximisation problem for society may be written as $max \sum_{i=1}^{n} ph_i - c_i(x, h_i)\ s.t.\ F(x) - \sum_{i=1}^{n} h_i = 0.$ The restriction may be solved for x to yield $x = M(h_i, h_{-i})$. Now $M(h_i, h_{-i})$ is an expression for how the steady-state stock size is related to catches and $\partial M/\partial h_i$ is a biological response function. The biological response function indicates how the steady-state stock responds to changes in individual catches. $M(h_i, h_{-i})$ may be substituted into the objective function to 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 $\partial c_i / \partial M\ \partial M / \partial h_i - \sum_{j \neq i} \partial c_j / \partial M\ \partial M / \partial h_i$ is the user cost of the fish stock. With respect

to fisherman i, f_i and h_i is the control variables and the maximisation problem may be written as

$$ph_i - c_i(N_i(h_i, \boldsymbol{h}_{-i}), h_i) - k_i(h_i)(\phi_i(x^* - N(h_i, \boldsymbol{h}_{-i}, \varepsilon_i)) - \sigma_{\varepsilon_i}{}^2 \phi_i''(x^* - N_i(h_i, \boldsymbol{h}_{-i}, \varepsilon_i))) - \tau_i f_i(h_i)$$

The first-order condition with respect to f_i and h_i is

$p - \partial c_i / \partial h_i - \partial c_i / \partial N_i \partial N_i / \partial h_i + k_i(h_i)(\phi_i'(\partial N_i / \partial h_i) + \phi_i'''(\partial N_i / \partial h_i) = 0$ and

$k_i'(h_i)\sigma_{\varepsilon_i}\phi_i''(0) + \tau_i = 0$. On basis of these conditions and the functions presented below the tax rates and functions can know be simulated.

The simulation requires knowledge of:

a. $M(h_i, h_{-i})$
b. $c_i(h_i, x)$
c. $N_i(h_i, h_{-i})$
d. ϕ_i
e. σ_ε

All details regarding the simulations are placed in appendix B. With respect to $M(h_i, h_{-i})$ a logistic growth function has been estimated, while the cost function has the following from:

$$c_i(x, h_i) = \alpha_i + \frac{\beta_i h_i^{\,2}}{x} \tag{34}$$

Individual cost functions has been estimated for the average vessel within the six groups.

Information about $N_i(h_i, h_{-i})$ is not directly obtainable, but it is assumed that $N_i(h_i, h_{-i}) = DM(h_i, h_{-i})$ and the simulations is conducted for:

- $D = 0.8$
- $D = 0.6$
- $D = 0.4$

What is new compared to Jensen and Vestergaard (2002) is that an estimate for ϕ_i and σ_ε is necessary. Information about ϕ_i and σ_ε is not directly obtainable and, therefore, reasonable functional forms and parameters must be selected. The following form of ϕ_i is selected:

$$\phi_i = a(N_i(h_i, h_{-i}) - x) + b\frac{\sigma_{\varepsilon_i}^{\ 2}}{2}(N_i(h_i, h_{-i}) - x)^2 \tag{35}$$

Now the parameters *a* and *b* is chosen such that a 50% reduction in the stock tax in Jensen and Vestergaard (2002) is obtained. It is, therefore, assumed that *a = 1,9998* and *b = 0.0001*. With respect to the variance, this is assumed to be small and, therefore, $\sigma_\varepsilon = 500$ tonnes.

Based on these functions the tax rates and functions can be calculated by inserting actual values for the variables h_i, h_{-i}, x *and* s_i. By using actual values an estimate for what the tax rate and functions, that secures the optimal catches in each year given the actual chosen variables, is obtained. In other words, the simulations depart from a disequilibrium assumption.

It has already been mentioned that the simulations departs from a function of ϕ_i that leads to a 50% reduction in the stock tax function in Jensen and Vestergaard (2002). Therefore, presentation of harvest tax rates is enough. For the period 1991-1997, these are presented in table 2.

Table 2. Harvest tax rates for the six groups of vessels, DKK per tonnes

		1991	1992	1993	1994	1995	1996	1997
Netters under 20 GT	D = 0.8	3.03	2.54	3.19	4.29	4.89	2.34	7.87
	D = 0.6	6.07	5.07	6.36	8.57	9.78	4.68	15.71
	D = 0.4	12.10	10.10	12.69	17.10	19.50	9.34	31.35
Netters over 20 GT	D = 0.8	9.02	7.53	9.45	12.74	14.53	6.96	23.36
	D = 0.6	17.95	14.99	18.83	25.37	28.92	13.86	46.51
	D = 0.4	35.57	29.70	37.3	50.27	57.29	27.47	92.15
Danish Seiners	D = 0.8	6.06	5.07	6.36	8.56	9.76	4.68	15.70
	D = 0.6	13.10	10.94	13.74	18.52	21.11	10.11	33.95
	D = 0.4	24.11	20.13	25.29	34.08	38.85	18.62	62.46
Trawlers under 50 GT	D = 0.8	4.55	3.80	4.77	6.43	7.33	3.51	11.78
	D = 0.6	9.08	7.58	9.52	12.83	14.63	7.01	23.51
	D = 0.4	18.09	15.11	18.97	25.56	29.15	13.96	46.85
Trawlers between 50 GT and 199 GT	D = 0.8	3.63	3.03	3.81	5.13	5.85	2.80	9.41
	D = 0.6	7.25	6.05	7.60	10.24	11.68	5.59	18.77
	D = 0.4	14.43	12.05	15.13	20.39	23.25	11.14	37.37
Trawlers over 200 GT	D = 0.8	3.65	3.05	3.83	5.16	5.89	2.82	9.46
	D = 0.6	7.91	6.05	9.08	9.88	9.88	4.73	18.02
	D = 0.4	14.59	12.19	15.30	20.62	23.51	11.26	37.80

From table 2 it is seen that the variable harvest tax rate is low compared to the sales price. With a sales price between 8,200 and 13,500 DKK per tonnes, the harvest tax is maximally 0.5 % of the sales price. The variation in tax rates between vessel groups is low, which could suggest a uniform tax. However, the simulations is based on a very simple assumption about $N_i(h_i, h_{-i})$, so this conclusion is not very useful. The harvest tax rate decreases in D. This conclusion is not surprising, because an increase in D decreases the market failure. The variation in the tax rates over time can be explained by variations in self reported harvest. If the self reported harvest is large, as in the early years, the tax rate becomes low.

But how sensible is the conclusion that the harvest tax rate is low to changes in the parameters. Jensen and Vestergaard (2002) show that a stock tax function is not very sensible to changes in the cost parameters. For this reason only sensibility analysis on ϕ_i and σ_ε is performed in this paper. Note that the parameter a in ϕ_i will not influence the self-reporting tax rate because this parameter is not included in ϕ_i''. Therefore, b is varied with +/- 50%. The results are presented in table 3. Because of lack of variations in the tax rates between vessel groups and years only the results for $s = 0.8$, Netters under 20 GT and 1997 is presented.

Table 3. Sensibility analysis for ϕ_i. D = 0.8, Netters under 20 GT, 1997, DKK per tonnes

	Tax rates
Main case	7.87
+ 50%	11.79
- 50%	5.90

It is seen that the variable tax rate increases with b. The reason for this is that an increase in b, increases the risk aversion. Therefore, the fisherman prefers the certain self-report tax payment and the tax rate is increased. Despite this fact the increase in the tax rate is low even for high increases in b.

But what about σ_ε? In table 4 the results obtained by varying σ_ε with +/- 50 % is reported.

Table 4. Sensibility analysis for σ_ε, D = 0.8, Netters under 20 GT, 1997, DKK per tonnes

	Tax rates
Main case	7.87
+ 50%	17.69
- 50%	1.97

Naturally the harvest tax rate increase with an increase in σ_ε. The increase is larger than the increase associated with an increase in b. The reason for this is that the stock tax function is unaffected by an increase in σ_ε. However, even by varying σ_ε with +/- 50%, the self-reporting tax rate still constitutes a very low share of the sales price.

To conclude, from table 2, 3 and 4 it is seen that the self-reporting tax rate is very low and, therefore, a combination of a stock and harvest tax may be a useful combination of management tools within fisheries.

6. Conclusion and discussion

In this paper, a stock tax function and a self-reporting tax rate have been combined to solve the stock externality problem, the problems with measurement of stock size and the problems with asymmetric information about individual catches. The stock and harvest tax system can be designed such that expected optimal individual catches is secured. This can not be accomplished within an ITQ system. Assume that a total quota is determined and this total quota is distributed to fishermen as ITQs. Now trade among quotas between fishermen will secure that the stock externality problem is solved. In addition, the stock uncertainty problem can be solved by maximising expected present value of resource rent. However, the problem of measuring individual catches is not solved be-

cause of the well-known problems of compliance with individual quota systems. Therefore, this paper indirectly argues that taxes may be preferred over ITQs to manage fisheries. However, the paper only gives one argument for taxes. The issue of the choice between price and quantity regulation are by no mean solved with the contribution in this paper because other kinds of uncertainty and asymmetric information can arise within fisheries. For example, Jensen and Vestergaard (2003) show that with uncertainty about the cost function nothing definite can be said about the choice between taxes and ITQs for a search fishery. It has also been shown that fishermen find it optimal to self-report a part of their catches if they are risk-averse. The explanation for this result is that in presence of stock uncertainty risk-averse fishermen will prefer a lower uncertain stock tax payment and, thereby, a higher certain harvest tax payment.

Two points are worth mentioning. First, the analysis in this paper is based upon an assumption that stock size is a random variable. In section 4 the risk aversion function was approximated with a second-order approximation around the optimal point. If this approximation shall be precise it requires that the random variation in stock size (the variance with respect to measuring the uncertain stock size) is small, but in reality the random variation in stock size may be large; see Anon (2002). However, the second-order approximation is only conducted in order to analyse the tax functions and rates with mathematics. The conclusion in the case where the measurement error associated with the stock size is large is that fishermen will increase their self-reported harvest if they are risk averse. However, this conclusion can only be arrived at formally by conducting an approximation of the risk-aversion function. Second, the analysis assumes risk-aversion among fishermen and this assumption can also be discussed. If vessels are risk-neutral, the fisherman will be indifferent between the stock tax payment and the self-reporting tax payment. Therefore, if the fishermen are risk-neutral the stock tax alone can secure optimal individual catches.

A criticism of the mechanism proposed in this paper can be that it does not secure budget-balance. This criticism is part of the motivation for the work by

Xepapadeas (1991), who proposes a random penalty mechanism to solve non-point pollution problems. Even though it is relevant to discuss this 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 other words, the social benefit from acting optimally is distributed back to, for example, the fishermen. In this manner, budget-balance can be secured.

Furthermore, the information requirements of the proposed tax mechanism could be discussed. This point is also part for the motivation for the work by Xepapadeas (1991). Within fisheries economics, taxes have traditionally been criticised for posing excessive information requirements, see Arnason (1990). The information requirements mentioned by Arnason (1990) can be seen from the model in this paper, because the user costs enter in the stock tax function and the user costs varies over time. However, the tax structure proposed in this paper raises even greater information requirements because society must have information about the individual risk aversion. This information can, however, be obtained in surveys. Furthermore, in practise the information requirements are not larger than any necessary information needed when the ambition is to regulate in an optimal fashion.

The discussion of information problems are related to the analysis by Cabe and Herriges (1992), who mention a problem in connection with non-point pollution. The tax mechanism proposed within the non-point pollution literature 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 other criteria are used to determine the quota (e.g. biological or political). All that is required is that individual catches are determined.

Despite these discussion points, combining several policy instruments to the solution of several market failure problems within fisheries is an important area for future research, because several market failure problems arise simultaneously in reality. For example, the optimal combination of instruments to the solution of problems with stock externalities, congestion and asymmetric information could be studied.

7. Literature

[1] Andersen, P. and Sutinen, J.G. (1984): *Stochastic Bioeconomics: A Review of Basic Methods and Results*, Marine Resource Economics, 1, pp. 117-136.

[2] Anon (2002): *Report of the Working Group of the Assessment of Demersal Stocks in the North Sea and Skagerak*, ICES.

[3] Anon (1997): *Fiskeriregnskabsstatistik*, SJFI.

[4] Arnason, R. (1990): Minimum Information Management in Fisheries, *Canadian Journal of Economics*, 3, pp 630-653.

[5] Arnason, R., Sandal, L.K., Steinshamn, S.I., Vestergaard, N., Agnason, S. and Jensen, F. (2000): *Comparative Evaluation of Cod and Herring Fisheries in Denmark, Iceland and Norway*, Report to the Nordic Council.

[6] Cabe, R. and Herriges, J.A. (1992): The Regulation of Non-Point Source Pollution under Imperfect and Asymmetric Information, *Journal of Environmental Economics and Management*, 22, pp. 134-146.

[7] Clark, C.W. (1990): *Matematical Bioeconomics. The Optimal Management of Renewable Resources*, John Wiley and Sons.

[8] Hansen. L.G., Jensen, F. Brandt, U.S. and Vestergaard, N. (2003*): Illegal Landings and Discard: A Self-Reporting Mechanism*, SØM Working Paper.

[9] Jensen, F. (2002): *Essays in Management of Fisheries under Imperfect Information*, University Press of Southern Denmark.

[10] Jensen, F. and Vestergaard, N. (2002): Moral Hazard Problems in Fisheries Regulation: The Case of Illegal Landings and Discard, *Resource and Energy Economics*, 24, pp. 281-299.

[11] Jensen, F. and Vestergaard, N. (2003): Prices versus Quantities in Fisheries Models, *Land Economics*, 79, pp. 415-426.

[12] Varian, H.R. (1992): *Microeconomic Analysis*. New York: Norton.

[13] Weitzman, M.L. (2002): Landing Fees vs. Harvest Quotas with Uncertain Fish Stocks, *Journal of Environmental Economics and Management*, 43, pp. 325-338.

[14] Xepapadeas, A.P. (1995): Observability and Choice of Instrument Mix in the Control of Externalities, *Journal of Public Economics*, 56, pp. 485-498.

[15] Xepapadeas, A.P. (1991): Environmental Policy under Imperfect Information: Incentives and Moral Hazard, *Journal of Environmental Economics and Management*, 2, pp. 113-126.

Appendix A.

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. Because of this assumption $\partial Q / \partial h_{it} < 0$ since $\partial^2 c_{it} / \partial h_{it} \partial x_{t+1} > 0$, while $\partial Q / \partial x_t > 0$ since $\partial^2 c_{it} / \partial x_1^2 < 0$. Furthermore, because of the same fact $\partial Q / \partial x_{t+1} < 0$.

By differentiating the stock and the self-report tax in the text (32 and 33) the following results is obtained:

$$\frac{\partial k_{it}}{\partial x_t} = \frac{\frac{\partial Q}{\partial x_t}(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}})) - \phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}})) - \phi_{it}''(\frac{\partial^2 N_{it}}{\partial h_{it}\partial x_t})Q}{(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''\frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))^2} < 0 \tag{A1}$$

$$\frac{\partial \tau_{it}}{\partial x_t} = -\frac{\partial k_{it}'}{\partial x_t}\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0) < 0 \tag{A2}$$

$$\frac{\partial k_{it}}{\partial x_{t+1}} = \frac{\frac{\partial Q}{\partial x_{t+1}}(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}}))}{(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''\frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))^2} > 0 \tag{A3}$$

$$\frac{\partial \tau_{it}}{\partial x_{t+1}} = -\frac{\partial k_{it}'}{\partial x_{t+1}}\frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}''(0) > 0 \tag{A4}$$

$$\frac{\partial k_{it}}{\partial h_{it}} = \frac{\frac{\partial Q}{\partial h_{it}}(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \frac{\sigma_{\varepsilon_t}^2}{2}\phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}})) - \phi_{it}'''(\frac{\partial N_{it}}{\partial h_{it}})) - \phi_{it}''(\frac{\partial^2 N_{it}}{\partial h_{it}^2})Q}{(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}'''\frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))^2} > 0 \tag{A5}$$

$$\frac{\partial \tau_{it}}{\partial h_{it}} = -k_{it}'' \frac{\sigma_{\varepsilon_t}^2}{2} \phi_{it}''(0) > 0 \tag{A6}$$

$$\frac{\partial k_{it}}{\partial \phi_{it}} = \frac{-\phi_{it}''(\frac{\partial N_{it}}{\partial h_{it}})Q}{(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))^2} < 0 \tag{A7}$$

$$\frac{\partial \tau_{it}}{\partial \phi_{it}} = -k_{it}' \frac{\sigma_{\varepsilon_t}^2}{2} \phi_{it}'''(0) > 0 \tag{A8}$$

$$\frac{\partial k_{it}}{\partial \sigma_{\varepsilon_t}} = \frac{-\frac{1}{2}\phi_{it}''(\frac{\partial N_{it}}{\partial h_{it}})Q}{(\phi_{it}'(\frac{\partial N_{it}}{\partial h_{it}}) + \phi_{it}''' \frac{\sigma_{\varepsilon_t}^2}{2}(\frac{\partial N_{it}}{\partial h_{it}}))^2} < 0 \tag{A9}$$

$$\frac{\partial \tau_{it}}{\partial \sigma_{\varepsilon_t}} = -k_{it}' \frac{\sigma_{\varepsilon_t}^2}{2} \phi_{it}''(0) > 0 \tag{A10}$$

Appendix B.

Simulation of the tax structure requires information about:

A. $M(h_i, h_{-i})$
B. $c_i(h_i, x)$
C. ϕ_i
D. σ_ε^2

In this appendix the estimations and assumptions behind the simulations is discussed.

A. $M(h_i, h_{-i})$
An expression for $M(h_i, h_{-i})$ requires information about a growth function. Information about stock size, x, and aggregated catches, H, is reported in table B.1.

Table B.1. Aggregated catches and stock size for cod in Kattegat

Year	X	H	*F(x)*
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	

Data for x is from the 1st of January, while data for H is from the 31st of December. It is, therefore, obtained that:

$$F(x_t) = x_{t+1} - x_t + H_t \tag{B1}$$

The data for $F(x_t)$ is also reported in table B.1.

On basis of the data in table B.1, a standard logistic growth function can be estimated. This function is given as:

$$F(x) = rx(1 - \frac{x}{K}) \tag{B2}$$

where:

r is the intrinsic growth rate
K is the carrying capacity

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

$$\begin{aligned} &r = 0.54\ (6.96) \\ &K = 170{,}496\ (1.19) \\ &R^2 = 0.51 \end{aligned} \tag{B3}$$

Note that K is insignificant. The reason for this is that K is large compared to x. From (B2) an expression for $M(h_i, h_{-i})$ may be found. The steady-state equation may be written as:

$$-\frac{rx^2}{K} + rx - \sum_{i=1}^{n} h_i \tag{B4}$$

Solving (B4) with respect to x and concentrating on the largest root because $F'(x) < 0$ yields:

$$M(h_i, \boldsymbol{h}_{-i}) = \frac{(r + (r^2 - \frac{4rh_i}{K} - \frac{4r\sum_{j \neq i} h_j}{K})^{0.5}}{\frac{2r}{K}} \quad \text{(B5)}$$

Information about $N_i(h_i,h_{-i})$ is not direct obtainable. It is therefore assumed that:

$$N_i(h_i, \boldsymbol{h}_{-i}) = DM(h_i, \boldsymbol{h}_{-i}) \text{ for } D \leq 1 \quad \text{(B6)}$$

The simulations are conducted for:

$$\begin{aligned} &D = 0.8 \\ &D = 0.6 \\ &D = 0.4 \end{aligned} \quad \text{(B7)}$$

B. $c_i(h_i, x)$
Now to the model for calibrating the cost function. A model from Arnason *et al* (2000) is used.

The profit function for fisherman *i* is:

$$\pi_i(h_i, x) = p_i h_i - c_i(x, h_i) \quad \text{(B8}$$

where p_i is a constant price.

The following cost function is assumed:

$$c_i(x, h_i) = \alpha_i + \frac{\beta_i h_i^2}{x} \quad \text{(B9)}$$

Inserting (B9) into (B8) yields:

$$\pi_i(h_i, x) = p_i h_i - \alpha_i - \frac{\beta_i h_i^2}{x} \quad \text{(B10)}$$

Data is only obtainable for five years. Therefore, data for 1997 is used to calibrate α_i and β_i.

There is data for average prices (p_i), average costs (s_i) and individual harvests (h_i). Therefore, an LP model can look like:

$$Max((p_i - s_i)h_i) \quad \text{(B11)}$$

s.t.

$$h_i \leq \bar{h}_i \quad \text{(B12)}$$

where $\bar{h}_i$ is the ration. The first-order condition of the LP-model is:

$$p_i - s_i - \lambda_i = 0 \quad \text{(B13)}$$

The first-order condition of (B10) is:

$$p_i - \frac{2\beta_i h_i}{x} = 0 \quad \text{(B14)}$$

Combining (B13) and (B14) yields:

$$\beta_i = \frac{(\lambda_i + s_i)x}{2h_i} \quad \text{(B15)}$$

$$\alpha_i = s_i h_i - \frac{\beta_i h_i^2}{x} \quad \text{(B16)}$$

Information about average prices and costs is obtained from Anon (1997). Table B.2 summarises the calculations of each of the six groups.

Table B.2. Cost data

	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
Gross output, cod 1000 DKK/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 1000 DKK/tonnes	10.6	13.5	11.2	8.2	8.6	8.9
Variable cost, cod 1000 DKK	670.8	2327.9	1820.9	1233.5	3059.6	7002.9
Share of cod	49.74	48.74	25.56	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

In table B.3 a time series for individual catches is reported.

Table B.3. Individual catches, tonnes

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

Running the LP-model yields the shadow prices reported in table B.4.

Table B.4. The shadow prices

	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 information from table B.1, B.2, B.3 and B.4 yields the cost function estimates reported in table B.5.

Table B.5. The calibration results

	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
α_i	150.07	426.46	198.51	195.75	233.29	31.82
β_i	2174.82	918.01	1575.59	869.87	744.62	4305.97

C. ϕ_i

It is not possible to obtain a measure for ϕ_i because the function captures the risk attitude of the fisherman. In the main text it was mentioned that the following assumptions must be fulfilled:

- $\phi_i(0) = 0$
- $\phi_i', \phi_i'' > 0$
- $\phi_i''' \geq 0$

Therefore, the following function is assumed:

$$\phi_i = 1.998(N_i(h_i, h_{-i}) - x) + 0.0001(N_i(h_i, h_{-i}) - x)^2 \quad \text{(B17)}$$

D. σ_ε^2

With respect to σ_ε^2 this parameter is set to 500 tonnes and the self reported harvest is taken to be 30% of the actual catches reported in table B.3.

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