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A Principal–Agent Analysis of Fisheries

by

FRANK JENSEN AND NIELS VESTERGAARD*

Very little principal–agent analysis has been done within the fisheries economic literature. This paper conducts a principal–agent analysis of fisheries. Within a standard principal–agent model, the low-cost agent must be allowed the same level of effort as under complete information. This conclusion does not hold for fisheries, because of a resource restriction and the fact that maximisation takes place over two variables. By means of comparative-static analysis, this paper argues that the low-cost agent must be allowed a larger effort than under complete information. (JEL: D 2, Q 2, L 5)

1 *Introduction*

There is a comprehensive economic literature on the management of fisheries resources. A basic point in this literature is that both a system of individual transferable quotas (ITQs) and a tax system secure a first-best optimum; see for example CLARK [1990]. The tax variable analysed is either the fishing effort or the harvest; see for example ANDERSEN [1979] and ANDERSON [1986]. The conclusions reached are based on the assumption that the regulatory authority has complete information about all variables relevant for regulation. As pointed out in ANDERSEN [1982], this assumption does not hold in reality, and the regulatory authority (society) often lacks information, particular about catches, costs, and productivity (catchability).

Analysis of regulation under incomplete information is normally conducted using a principal–agent approach; see LAFFONT AND TIROLE [1993]. In such an analysis it is possible to design an incentive scheme that takes incomplete information into account. This paper applies the principal–agent approach to studies of fisheries management and concentrates on incomplete information about a technical and exogenous cost parameter. When incomplete information about an exogenous variable is analysed, an adverse selection problem arises; see for example HANLEY, SHOGREN, AND WHITE [1997]. Discard and illegal landings mean that catches cannot be observed, and this problem is analysed in JENSEN AND VESTERGAARD [2000]. Incomplete information about a catchability coefficient can be analysed in the same

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way as the analysis of incomplete information about a cost parameter presented in this paper.

That an adverse selection problem with respect to costs arises within fisheries can easily be seen. For many fisheries, cost data is not collected, and for fisheries where cost data is collected, the data collection is often based on statements by the fishermen. Assume now that the fishermen pay a tax on the basis of the stated costs and that the true cost type of the vessels is unobservable.[1] In this case it is possible that the high-cost agent pretends to be a low-cost agent because it can decrease total tax costs. Therefore, adverse selection of vessels arises. It must now be in the interest of society to design the tax so that the vessels get an incentive to reveal the type correctly, and hence incentive-compatibility restrictions are included in the problem. Valuable information is thus collected, but the price of collecting this information is that an information rent must be paid.

Taxes and subsidies often constitute the incentive schemes analysed in fisheries economics, and two problems associated with these regulatory instruments are often mentioned.[2] First, the information requirements are substantial and have been criticised; see CLARK [1990]. With a principal–agent approach it is possible to solve this problem, since taxes and subsidies can be designed to secure correct revelation of private information. Hence, the regulatory authority uses the tax structure to collect valuable information. The price for solving the information problem is that an information rent must be given, since the actors must be given an incentive to reveal their types correctly. Second, the distributional implications of taxes and subsidies have been criticised; see CLARK [1990]. With taxes the fishermen only get inframarginal rents, and with subsidies the fishermen get large rents. Applying a principal–agent approach can also solve these problems. In such an analysis it is common to include a participation restriction with a reservation utility; see VARIAN [1996]. By proper choice of the reservation utility, parts of the resource rent can be allocated to the fishermen.

Only two principal–agent analyses are found in the fisheries economic literature. CLARKE AND MUNRO [1987] conduct an analysis under complete information and combine the use of a harvest and effort tax.[3] Clearly the information requirements of this structure can be questioned, and an incomplete information approach seems more appropriate. Clarke and Munro also call for models that include uncertainty. Furthermore, the feasibility of taxing the harvest can be questioned, because

[1] An alternative approach would be to assume that the agents give off signals that allow the principal to induce the type of the agents. However, studies of fisheries management with a principal–agent approach are a new research area and therefore signalling is excluded in this paper.

[2] A third problem that is mentioned in association with taxes and subsidies is that random fluctuations in stock size within a season make continual adjustment of the tax and subsidy rates necessary. However, random fluctuations in stock size also generate problems for ITQs, since quotas must be continually adjusted.

[3] In the literature there is some confusion with respect to the definition of a principal–agent analysis. In this paper principal–agent analysis is defined by the inclusion of participation and incentive compatibility restrictions.

catches, in practice, are not measurable due to illegal landings and discard; see JENSEN AND VESTERGAARD [2000] and COPES [1986]. Therefore, effort is chosen as the tax/subsidy variable in this paper. But is effort observable? Naturally the answer is no, since effort is a multidimensional variable. However, a tax system can be designed on the basis of a proxy for effort, and following the work by DUPONT [1991], days at sea can be a proxy for effort because of the sign and magnitude of the substitution elasticities in the short run.[4] In a study of an EU effort tax, JENSEN AND VESTERGAARD [1999] adopt the assumption that an adverse selection problem arises because there is incomplete information about a technical and exogenous cost parameter. In traditional adverse selection models, the low-cost agent must be allowed the same level of effort as under complete information; see for example VARIAN [1996]. The reason for this is that there is only one choice variable and no restriction on the maximisation problem. However, JENSEN AND VESTERGAARD [1999] indicate that for fisheries this result does not hold, because a resource restriction is included in the maximisation problem. Furthermore, there are two choice variables and a Lagrange multiplier that can be different between models of complete and incomplete information. By means of comparative-static analysis, it is argued in this paper that the low-cost agent must be allowed a larger effort than under complete information in order to fulfil the resource restriction.

It is surprising that only two principal–agent analyses of fisheries exist in the literature, in view of the large pollution control literature applying a principal–agent approach. The purpose of the pollution literature is to try to design a regulatory system that secures a second-best optimum in the light of incomplete information. Within the pollution control literature, two approaches exist. The first approach uses general functions to arrive at a general indication of what variables must be included in the regulatory system. JEBJERG AND LANDO [1997] and LAFFONT [1994] are examples of such an approach. The second approach uses specific functional forms to arrive at a specific expression of, for example, a tax system; see SPUBLER [1988]. The analysis in this paper is conducted using general functional forms and is thereby in line with the first approach. However, irrespective of whether general or specific functions are used, the low-cost agent will be allowed the same level of effort as under complete information when analysing pollution with a simple principal–agent model. The reason for this is that no restrictions are included in the maximisation problem and that pollution control effort is the only choice variable. In other words, the literature considers a flow, not a stock, pollution problem, and the fisheries problem is a stock–flow problem.

The structure of the paper is as follows. In Section 2 a principal–agent analysis of fisheries is given and the results of a comparative static analysis are presented. Section 3 concludes the paper.

[4] It can be argued that effort is only verifiable by observing catches. However, this conclusion is not correct because days at sea are observable by counting at ports and by satellite monitoring. Therefore, effort is observable even though catches are unobservable.

2 An Adverse-Selection Model for Fisheries

As JENSEN AND VESTERGAARD [1999] discuss, studying the management of a fisheries resource with a principal–agent approach gives the result that the low-cost agent must not be allowed the same level of effort as under complete information. To analyse this result, a variant of the models in SMITH [1968] and [1969] and BROWN [1974] is presented. It is assumed that society collects the revenue generated by the fishermen, but pays a subsidy to the fishermen. The fishermen bear the costs associated with the fishery, but receive the payment from society. In other words, a centrally owned fishery resource is considered, and this directly corresponds to the use of a standard principal–agent model. Note that the assumptions selected will result in a first-best optimum under complete information.

A criticism of taxes and subsidies within fishery economics is that they pose too large information requirements. ARNASON [1990] mentions costs as a parameter that society has little information about. By conducting an analysis under adverse selection, it is possible to solve this problem, and therefore, an analysis under incomplete information is now considered.

Assume that society knows that fisherman i belongs to one of two types, a low-cost type 1 or a high-cost type 2. Society has incomplete information about the type of fisherman i, and π_1 and π_2 denote the probabilities of types 1 and 2.[5] It is assumed that $C_{i1}(E) < C_{i2}(E)$ for all E, where $C_{i1}(E)$ and $C_{i2}(E)$ are the cost functions for types 1 and 2, and E is the fishing effort. Furthermore, it is assumed that the single-crossing property is fulfilled such that $C_{i1}'(E) < C_{i2}'(E)$. The basic incentive problem is that the low-cost agent may pretend to be a high-cost agent because a benefit can be obtained by doing so. The society disregards discounting,[6] and therefore the maximisation problem (the maximisation takes place over the individual effort levels, stock sizes, and individual subsidies) is:

$$(1)\qquad \max \sum_{i=1}^{n} (\pi_1(pG_{i1}(x, E_{i1}) - S_{i1}(E_{i1})) + \pi_2(pG_{i2}(x, E_{i2}) - S_{i2}(E_{i2})))$$

subject to:

$$(2)\qquad F(x) - \sum_{i=1}^{n} (\pi_1 G_{i1}(x, E_{i1}) + \pi_2 G_{i2}(x, E_{i2})) = 0\,,$$

$$(3)\qquad S_{i1}(E_{i1}) - C_{i1}(E_{i1}) \geq 0 \quad \text{for all low-cost agents,}$$

$$(4)\qquad S_{i2}(E_{i2}) - C_{i2}(E_{i2}) \geq 0 \quad \text{for all high-cost agents,}$$

[5] A more general case would be to allow for a continuum of types. However, allowing for a continuum of types does not qualitatively change the effort result, see JEBJERG AND LANDO [1997].

[6] In other words long-run yield is maximised. In fisheries economics it is common to include a discount rate, and optimal control theory can be used to solve the problem, see for example CLARK [1990]. A discount rate of zero is assumed in order to keep the analysis as simple as possible.

(5) $\quad S_{i1}(E_{i1}) - C_{i1}(E_{i1}) \geq S_{i2}(E_{i2}) - C_{i1}(E_{i2})$ for all low-cost agents,

(6) $\quad S_{i2}(E_{i2}) - C_{i2}(E_{i2}) \geq S_{i1}(E_{i1}) - C_{i2}(E_{i1})$ for all high-cost agents,

where x is the fishery stock, and $G_i(x, E_i)$ is the catch (production) function for fisherman i. The catch is a function of stock size and effort, and it is assumed that $\partial G_i/\partial x > 0$, $\partial G_i/\partial E_i > 0$, $\partial^2 G_i/\partial E_i^2 \leq 0$, and $\partial G_i/\partial x\, \partial E_i > 0$. (The marginal product of stock size is positive, and the marginal product of effort is positive and nonincreasing. Furthermore, stock size and effort are complements in the production of catches.) $F(x)$ is the natural growth of the stock, p is the price, and $S_{ih}(E_{ih})$ is the subsidy to type $h = 1, 2$.

Equation (2) is a resource restriction expressing that the natural growth rate must be equal to the sum of expected catches. The implication of equation (2) is that the principal wants a steady-state equilibrium.[7] Equations (3) and (4) are the participation restrictions for each agent. The participation restrictions will secure the survival of each individual fisherman. It is often argued that fishery taxes are impossible to implement because they exhaust the fishermen's rent, and subsidies will allocate an undesired high proportion of the resource rent to the fishermen. With a participation restriction, it is possible to solve these problems. Since the reservation utility is a constant, it will not influence marginal incentives, and can be selected arbitrarily. Therefore, by proper selection of the constant, any desired rent can be allocated to the fishermen. In equations (3) and (4) the constant is set to zero, but this can be seen as a result of normalisation. Equations (5) and (6) are the self-selection restrictions (incentive-compatibility restrictions) expressing that the fishermen must have an incentive to reveal the correct type.

In the appendix it is shown that the participation restriction of type 2 and the self-selection restriction of type 1 are binding irrespective of the presence of the resource restriction.[8] This means that

(7) $\quad S_{i2}(E_{i2}) = C_{i2}(E_{i2})$ for all high-cost agents,

(8) $\quad C_{i1}(E_{i1}) + (C_{i2}(E_{i2}) - C_{i1}(E_{i2})) = S_{i1}(E_{i1})$ for all low-cost agents.

Equation (7) indicates that the subsidy is designed in such a way that the high-cost agent receives the allocated resource rent, and (8) shows that the low-cost agent receives an information rent, because $C_{i2}(E_{i2}) - C_{i1}(E_{i2}) > 0$. This information rent is the cost difference between types, evaluated at the effort level for type 2. This difference gives an incentive for type 1 to reveal his type correctly, and is the price that society pays to secure correct revelation of types.

By substituting (7) and (8) into (1), a rewritten optimisation problem is obtained. Now a Lagrange function can be set up, and the principal's first-order conditions with respect to agent i are:

(9)
$$\frac{\partial L}{\partial E_{i1}} = \left(p\frac{\partial G_{i1}}{\partial E_{i1}} - \frac{\partial C_{i1}}{\partial E_{i1}}\right) - \lambda\frac{\partial G_{i1}}{\partial E_{i1}} = 0\,,$$

(10)
$$\frac{\partial L}{\partial E_{i2}} = \frac{\pi_1}{\pi_2}\left(\frac{\partial C_{i1}}{\partial E_{i2}} - \frac{\partial C_{i2}}{\partial E_{i2}}\right) + \left(p\frac{\partial G_{i1}}{\partial E_{i2}} - \frac{\partial C_{i2}}{\partial E_{i2}}\right) - \lambda\frac{\partial G_{i2}}{\partial E_{i2}} = 0\,,$$

(11)
$$\frac{\partial L}{\partial x} = \sum_{i=1}^{n}\pi_1 p\frac{\partial G_{i1}}{\partial x} + \sum_{i=1}^{n}\pi_2 p\frac{\partial G_{i2}}{\partial x} + \lambda\left(F'(x) - \sum_{i=1}^{n}\left(\pi_1\frac{\partial G_{i1}}{\partial x} + \pi_2\frac{\partial G_{i2}}{\partial x}\right)\right) = 0\,,$$

(12)
$$\frac{\partial L}{\partial \lambda} = F(x) - \sum_{i=1}^{n}(\pi_1 G_{i1}(x, E_{i1}) + \pi_2 G_{i2}(x, E_{i2})) = 0\,.$$

Society wants to set the expected marginal benefits for effort equal to the marginal costs. For type 1 the expected marginal benefit for effort consists of the expected marginal resource rent $(p\partial G_{i1}/\partial E_{i1} - \partial C_{i1}/\partial E_{i1})$. The marginal costs are the user costs $(\lambda(\partial G_{i1}/\partial E_{i1})$. For type 2 there is an extra cost. Because type 1 is present and must be given an incentive to reveal his type correctly, the first-order condition for type 2 must be corrected by the marginal incentive costs $(\pi_1/\pi_2(\partial C_{i1}/\partial E_{i2} - \partial C_{i2}/\partial E_{i2}))$. Equations (9) and (10) correspond to a second-best optimum. The expected marginal benefits of stock size are the expected value of increased catches with increased stock size $\left(\sum \pi_1 p\partial G_{i1}/\partial x + \sum \pi_2 p\partial G_{i2}/\partial x\right)$. The marginal cost of stock size is the value of the effect on the resource restriction $\left(\lambda(F'(x) - \sum(\pi_1 \partial G_{i1}/\partial x + \pi_2 \partial G_{i2}/\partial x)\right)$. Note that $F'(x) < 0$ in optimum.

A result in standard principal–agent models is that type 1 must be allowed the same level of effort as under complete information; see VARIAN [1992]. Even though the first-order condition for type 1, if the participation restriction is binding, is $p\partial G_{i1}/\partial E_{i1} - \partial C_{i1}/\partial E_{i1} - \lambda\partial G_{i1}/\partial E_{i1} = 0$, this result does not hold for fisheries, for two reasons. First, λ creates an interaction between the first-order conditions for effort and the first-order condition for stock size, and λ may be different between the models of complete information and incomplete information. Second, equation (11) can depend on the stock size, and the optimal stock size can be different between the models. For these reasons it is interesting to compare the effort level under complete information with E_{i1}.

But how can a complete-information model be compared with an incomplete information model? Following SUTINEN AND ANDERSEN [1984], the models can be compared by means of a shifting variable, ϕ. The main difference between the two models is that the marginal incentive costs are included in the first-order condition for type 2 under incomplete information. The shifting variable is now introduced in the maximisation problem in front of the incentive costs, and $\phi = 1$ in the case of incomplete information, while $\phi = 0$ in that of complete information.

[7] Within fisheries economics it is common to discuss adjustment towards equilibrium. However, this paper restricts attention to steady-state equilibrium, since it is a first attempt to study management of fisheries with a principal–agent approach.

[8] This means that the participation restriction of the high-cost agent and the self-selection restriction of the low-cost agent are the only restrictions to be included in the maximisation problem of the principal.

Now a comparative-static analysis can be performed, and it can be shown that[9]

$$\frac{dE_{i1}}{d\phi} > 0, \tag{13}$$

$$\frac{dE_{i2}}{d\phi} < 0, \tag{14}$$

$$\frac{dx}{d\phi} > 0. \tag{15}$$

In order to understand these results, it is useful to start with equation (14). Because $dE_{i2}/d\phi < 0$, the effort level for type 2 is larger under complete information than under incomplete information. The reason for this is that an extra cost is included in the first-order condition in the incomplete information model (the marginal incentive costs). However, a resource restriction saying that $F(x) - \sum(\pi_1 G_{i1}(x, E_{i1}) + \pi_2 G_{i2}(x, E_{i2})) = 0$ is included in the maximisation problem, and because E_{i2} is larger in the complete information model than in the incomplete information model, it must be expected that E_{i1} is larger under incomplete information than under complete information in order to fulfil the restriction. Therefore, $dE_{i1}/d\phi > 0$ (equation (13)). Turn now to the aggregated effort. Because an extra cost is present for type 2, it must be expected that the aggregated effort is lower. The implication of this is that the steady-state stock size is larger under incomplete information than under complete information. Equation (15) confirms this result.

Note that this result is not sensitive to the formulation of the resource restriction for well-specified models. Assume that the fishery is away from steady state and that adjustments toward equilibrium are allowed. Now $dx/dt = F(x) - \sum(\pi_1(x, E_{i1}) + \pi_2 Gi_2(x, E_{i2}))$, and there will exist an optimal adjustment path toward equilibrium for both complete and incomplete information. However, irrespective of the paths, $dE_{i1}/d\phi > 0$. The reason for this is that an extra cost is present for type 2 under incomplete information and the resource restriction must be fulfilled.

3 Conclusion

This paper presents a principal–agent analysis of fisheries under adverse selection. It is argued that the low-cost agent must be allowed a larger effort under incomplete information than under complete information, in order to fulfil the resource restriction. This result is contrary to the standard principal–agent result where the low-cost agent must be allowed the same level of effort.

Principal–agent analysis of fisheries is a useful tool because it is possible to take into account huge information requirements and it is possible to allocate parts of the resource rent to the fishermen. However, the model has several limitations. First, it is assumed that only two types of agents exist. Theoretically, it would be more correct to work with a continuum of types. Second, discounting is excluded and long-run economic yield is maximised. In fisheries economics it is common to include discounting. Third, discussion of adjustment towards steady-state equilibrium is excluded. Here discussions of feedback rules in the light of complete information seem to be the correct approach. Fourth, signalling is assumed away. In reality, the principal can deduce something about the type of the agent by observing, for example, technology. The assumptions of two types, no signalling, no discounting, and steady-state equilibrium are explained by the fact that the assumption about complete information has been relaxed but a future research area is to work with, for example, feedback rules in the light of imperfect information.

Despite the fact that the analysis is conducted under incomplete information, the information requirements of the proposed subsidy may be questioned for three reasons. First, the subsidy requires knowledge of, for example, individual production functions. However, this information requirement is by no means higher than in other attempts to manage in an optimal fashion. Second, the feasibility of a nonlinear, individual subsidy may be questioned. A solution to this problem is to use a two-part linear subsidy that is uniform within homogeneous groups. Third, the maximisation takes place over individual vessels. However, as above, combining vessels into homogeneous groups can be a solution.

In the analysis in this paper a second-best optimum is reached by designing a tax system that incorporates incomplete information. In their work on pollution control, Roberts and Spence [1976] and Kwerel [1977] conclude that several regulatory instruments can be combined to reach a first-best optimum. Combining regulatory instruments for a renewable resource such as fisheries might prove to be useful.

Appendix

For type 1, self-selection and participation restrictions are present, and these may be written as:

$$S_{i1}(E_{i1}) \geq C_{i1}(E_{i1}), \tag{A1}$$

$$S_{i1}(E_{i1}) \geq C_{i1}(E_{i1}) + (S_{i2}(E_{i2}) - C_{i1}(E_{i2})). \tag{A2}$$

Since the payment enters with a negative sign, according to the principal's objective function, one of these restrictions is binding.

According to the participation restriction for type 2,

$$S_{i2}(E_{i2}) - C_{i2}(E_{i2}) \geq 0. \tag{A3}$$

The single-crossing property implies that

$$-C_{i1}(E_{i2}) > -C_{i2}(E_{i2}). \tag{A4}$$

Equations (A3) and (A4) imply that

$$S_{i2}(E_{i2}) - C_{i1}(E_{i2}) > S_{i2}(E_{i2}) - C_{i2}(E_{i2}) \geq 0. \tag{A5}$$

[9] The results of the comparative-static analysis are available from the authors.

Therefore, the expressions in the bracket of equation (A2) are positive, and it must be the self-selection restriction that is binding for type 1.

Since payment enters with a positive sign, one of the restrictions for type 2 must be binding. Can it be the self-selection restriction? If this restriction is binding and the binding self-selection restriction of type 1 is substituted into the self-selection restriction for type 2, the following is obtained:

$$C_{i1}(E_{i2}) - C_{i1}(E_{i1}) = C_{i2}(E_{i2}) - C_{i2}(E_{i1}) \,. \tag{A6}$$

This violates the single-crossing property. It must therefore be the participation restriction for type 2 that is binding.

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