Regulation of Renewable Resources in Federal Systems: The Case of Fishery in the EU[1]

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Abstract

The EU regulation of fisheries is decided in two levels. The level of the total allowable catch (TAC) for the most important species is decided every year by the Council of Minsters. The TACs are allocated to the Member States as quotas. The Member States determine who is going to harvest the quota. There is, however, an information problem associated with this structure. It does not take into account how efficient fishermen in different countries are. In this paper we model the information problem as an adverse selection problem and analyse an EU tax coupled to effort as an alternative to the TAC system. We work with the hypothesis that EU suffers from a fiscal illusion and includes tax revenue in the objective function in order to finance other, also inefficient, operations. Even in the light of these imperfections there are at least two reasons for recommending an EU tax. First, it can be used to correct part of the market failure associated with fishery. Second, it can be used to secure correct revealation of types in the light of asymmetric information.

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1 Introduction

The EU regulation of fisheries is decided on two levels. For example, the level of the total allowable catch (TAC) for the most important species is decided every year by the Council of Ministers. The TACs are allocated as quotas to the Member States. The Member States then determine which fishermen are going to harvest the quota. The main purpose with the TACs is to protect the stocks.

There are several problems with this scheme. It does not take into account how efficient fishermen in different countries are. The allocation scheme (called relative stability) was established in 1983 and has not been changed since. There are incentives in a quota management system to high grade and illegal landings[2]. Further, the Member States do not have incentives to conduct an effectient control and enforcement system. Generally speaking, the allocation scheme does not solve the general common property problem of the fisheries.

A more efficient system using the TAC framework is to use information from each Member State about the efficiency of the fishermen to decide on the allocation of TACs. However, this information might be biased, i.e. an asymmetric information problem is present. In the present paper this information problem is handled by setting up an incentive scheme based on taxes on effort. In other words we wish to study a tax system as an alternative to the TACs.

We model the information structure in the EU as an adverse selection problem (imperfect information about an exogenous cost parameter).

2 See Coopes (1986) and Kommissionen (1992)

One can question if this is the right information hypothesis to use with regard to the information problems associated with fishery regulation. However the analysis must be seen as a first attempt to analyze a double principal-agent relation (section 4) within fishery regulation. The adverse selection hypothesis is selected in order to make models as simple as possible. For the same reason the focus in this paper is on the calculation and evaluation of marginal taxes.

Some comments to the literature relevant for this paper. Within the traditional environmental economics there is some discussion of optimal regulation in the light of asymmetric information, see e.g. Roberts and Spence (1976), Kwerel (1977) and Jebjerg and Lando (1997). Roberts and Spence (1976) and Jebjerg and Lando (1997) combine the use of transferable pollution permits and taxes/subsidies to arrive at a first-best optimum. An assumption here is, however, that there are no market failures in the market for pollution permits, which is a restrictive assumption, see Dasquata *et al* (1980). Others therefore prefer to use one economic instrument and analyze a second-best optimum in the light of asymmetric information. E.g. Jebjerg and Lando (1997) conduct a principal-agent analyze of taxes under moral hazard and adverse selection. Our analyis is in line within the principal-agent analysis in Jebjerg and Lando (1997), but differs in two respects. First, we are interested in taxing a renewable resource. Second, the models are not purely normative. Even though the EU is interested in correcting a market failure, it also suffers from a fiscal illusion and include tax revenue in the objective function. We, however, find optimal regulation for a natural resource a very promising research area.

Within environmental economics there is also some discussion about central versus decentral regulation in the light of asymmetric information, see Jeppesen (1997), List (1997), Klibanoff and Poitevin (1995), Rob (1989) and Farrell (1987). One main conclusion within this literature is that imperfect information at the federal level can be an argument for decentral regulation. Our analysis differs from these since we are interested in discussing taxing of a natural resource from the point of view of the federal level.

Within fishery economics a game theoretical framework is normally used to analyze the relation between countries, see e.g. Naito and Polansky (1997), Munro (1996) and Kaitala (1986). These authors normally compare a cooperative and a non-cooperative solution to the fishery game under full information and try to discuss instruments that might induce the cooperate solution. Here we use a principal-agent approach and analyze the relation between a federal and local governmental level under asymmetric information.

In section 2 we will introduce the model that is used with an analysis of full information, while section 3 contains a simple adverse selection model where the Member States disregard the resource restriction. In section 4 we will analyze a more advanced adverse selection model.

2 Introduction to the model – full information

We will set up a model with short run production functions inspired by Andersen (1979), where the stock for fishermen j in country i is exogenous given. On the EU level the total production is assumed to be equal to the growth of the stock, i.e. the model is in biological and economic equilibrium. The reason for selecting this model is that it is well suited for analyzing problems of asymmetric information, since it does not include dynamic aspects.[3]

The first question we encounter is how to model the Member States. One could use a traditional open access assumption between Member States.[4] We will not do this, as the analysis is not purely normative. In reality, EU is engaged in various entry and exit adjustment programs such as the MAGP. [5] We will therefore assume that we have an industry in country i with k fishermen. But what shall we assume that the Member States maximize? Clearly, the resource rent must be incorporated, but unlike the case for most traditional fishery economics, the EU tax is not purely set for reasons of economic efficiency, and we will subtract tax costs from the resource rent. This choice appears to be consistent with the theory of regulation of firms under asymmetric information.[6] In this and the following section, we will assume that the Member States totally disregard the resource restriction. We therefore assume that Member States i maximize:

$$\max_{E_i} \sum pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - T_{ij}(E_{ij}) \qquad (1)$$

Where

x is the fish stock
E_{ij} is the level of effort for the fishermen j of country i

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3 Dynamic models may be found many places in the litterature, see e.g. Conrad and Clark (1987).
4 See e.g. Clark (1982) and Anderson (1995) for a discussion of open access models.
5 See Frost *et al* (1995) for an evaluation of the decomposion scheme in Denmark and the Netherlands, and Holden (1994) for an overview over the MAGP-program.
6 See e.g. Laffont and Tirole (1993).

p is an exogenous price

$G_{ij}(x,E_{ij})$ is a short-run production function relating catch for fishermen j in country i, G_{ij}, to the stock and effort, see Andersen (1979).

We will assume that $\delta G_{ij}/\delta E_{ij} > 0$, $\delta^2 G_{ij}/\delta E_{ij}^2 = 0$, $\delta G_{ij}/\delta x > 0$ and $\delta^2 G_{ij}/\delta x \delta E_{ij} = q$. In other words, we operate with the production function $G_{ij} = qE_{ij}x$, where q is the catchability coefficient. This function is often used within biological fishery models. Remark that catch is linear in both effort and stock.

$C_{ij}(E_{ij})$ is the cost function for effort for fishermen j in country i. It is assumed that $C_{ij}' = c_{ij}$ and $C_{ij}'' = 0$ for $E < \underline{E}$ and $C_{ij}' \rightarrow \infty$ for $E = \underline{E}$. $\underline{E}$ can be interpreted as a capacity limit for effort – an assumption that is used within the literature on public enterprise economics.[7] In other words we assume constant marginal costs up to a capacity limit.

$T_{ij}(E_{ij})$ is the EU tax function. Note that EU taxes fishery effort, and that we imagine a system where the EU taxes the Member States on the basis of individual fishermen. At the moment it may seem more reasonable to work at macro level, but when we come to the more advanced model in section 4, the reason for this will become clear. Further, the difference will vanish in the case where fishermen are homogeneous. Note also that we imagine a non-linear tax system in E_{ij}.

The first order condition is:

$$p\delta G_{ij}/\delta E_{ij} - c_{ij} - T_{ij}'(E_{ij}) = 0 \qquad (2)$$

7 See e.g. Rees (1984).

The condition indicates that the value of the marginal product for effort is set equal to the marginal costs, which include the marginal tax costs. A marginal tax on $T_{ij}'(E_{ij})$ in the optimal point will generate E_{ij} units of effort and the resource rent will be $(p\delta G_{ij}/\delta E_{ij} - c_{ij})E_{ij}$. In the following we assume that the marginal tax is such that $E_{ij} < \underline{E}$, where the capacity limit is the level of effort chosen without regulation. The basic welfare economic problem is that effort is too large in the unregulated model (the Member States do not include the effects on the fish stock).

How do we model the EU? If we use a traditional normative approach as in Jebjerg and Lando (1997), we should assume that the EU maximizes the sum of the Member States welfare corrected with a shadow multiplier in front of public funds. We will not do so since we are also interested in conducting a positive analysis of the tax. Clearly, maximization of the resource rent must be incorporated. We will also assume that the EU suffers from some degree of fiscal illusion with respect to fishermen's tax costs. Following Segerson *et al* (1997), we define a fiscal illusion as a situation where the EU only incorperates a part of the costs incurred by the Member States. In other words the fiscal illusion hypothesis means that EU does not full take into account the tax costs of the Member States when maximizing the benefit. $\mu < 1$ captures the degree of the fiscal illusion – if μ is large, the fiscal illusion is small. μ may also be interpreted as compliance and enforcement costs associated with letting the EU tax the Member States on the basis of individual fishermen. We will also include the tax revenue from the Member States as a benefit for EU. From the normative perspective this might be explained with the double dividend hypothesis, but a more reasonable explanation is that the EU wishes to finance other, also inefficient operations, with the tax revenue. The incorporation of tax revenue is therefore in line with the hypothesis of a budget maximization bureaucrat in Niskanen (1971). Thus, our analysis is a mix between a normative and positive approach. Note, however that the model may be given a normative interpretion with a double dividend hypothesis and compliance and enforcement cost. Consequently, it is assumed that the EU will maximize:

$$\max_{E_{ij},\, x,\, T_{ij}} \sum\sum pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) + (1 - \mu)T_{ij}(E_{ij}) \tag{3}$$

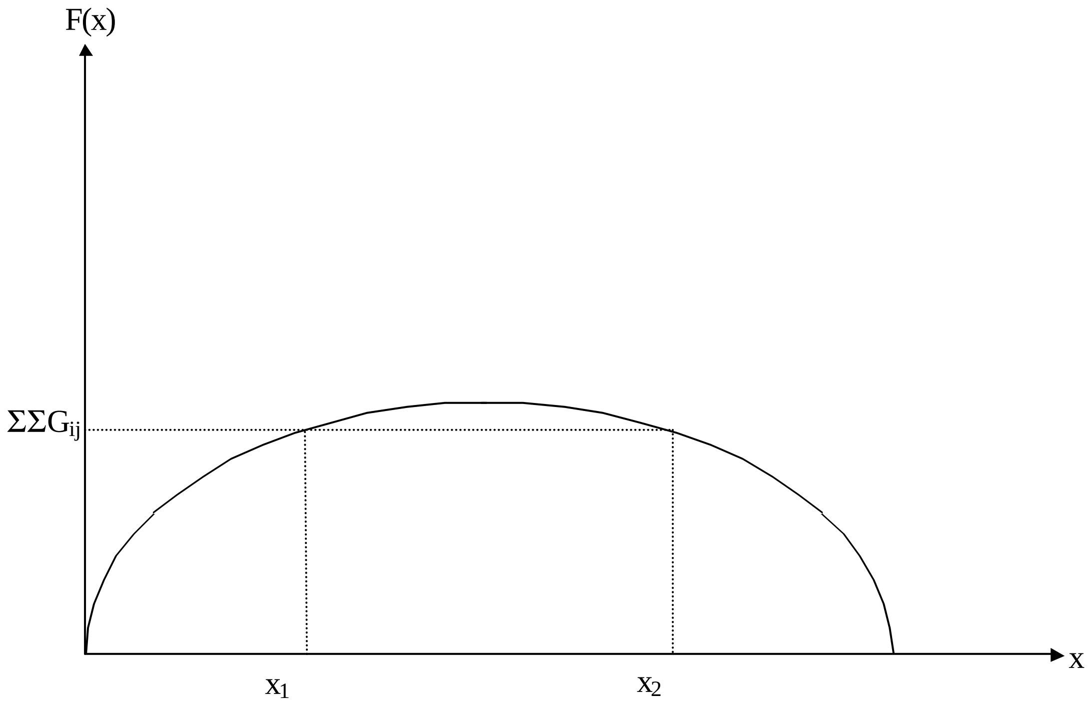
$$dx/dt = F(x) - \sum\sum G_{ij}(x, E_{ij}) = 0 \tag{4}$$

$$pG_{ij}(x, E_{ij}) - C_{ij}(E_i) - T_{ij}(E_{ij}) \geq 0 \text{ for all } j = 1,\ldots..,k \text{ and } i = 1,\ldots..,n \tag{5}$$

In (4), F(x) is the natural growth rate of the fishery stock and it is assumed that it will follow a standard logistic form. F(x) is drawn in figure 1.

The implication of (4) is that we search for a steady-state equilibrium, where the natural growth rate is equal to catch so that the stock is either x_1 or x_2. Note that the maximization procedure implies that we choose x_2. The implication of this is that in optimum the stock would be set where $F'(x) < 0$.

Figure 1: The logistic growth function



5) is a participation restriction, which is standard in principal-agent analyses, see Varian (1992). We have formulated the participation restriction as a condition that every fisherman must earn a non-negative resource rent net of taxes. Alternatively, the restriction could have been formulated as a non-negative benefit for the Member States ($\sum(pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - T_{ij}(E_{ij}) \geq 0$). The formulation in (5) says that the EU does not want to give the Member States any incentive to drive their fishermen out of the market – the Member States is secured a non-negative benefit for every fisherman. (5) is stronger than a non-negative benefit to the Member States, since the sum of the restrictions for all k fishermen in country i is $\sum(pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - T_{ij}(E_{ij}) \geq 0$. For reasons of simplicity we have set the reservation utility to zero. Alternatively, we could have interpreted the zero as a result of normalization. As taxes shall be as large as possible, according to the objective function, the participation restriction will always be binding:

$$T_{ij}(E_{ij}) = p\,G_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) \qquad (6)$$

The implication of (6) is that the Member States' resource rent is taxed away. From the point of view of the EU this represents a benefit, but for the Member States it is a drawback.

By substitution (6) into (3) we obtain the following maximization problem:

$$\underset{E_{ij},\, x}{\text{Max}} \sum\sum pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) + (1-\mu)(pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij})) \qquad (7)$$

s.t.

$$F(x) - \sum\sum G_{ij}(x, E_{ij}) = 0 \qquad (8)$$

The lagrange function may be written as:

$$L = \sum\sum pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) + (1-\mu)(pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij})) + \lambda(F(x) - \sum\sum G_{ij}(x, E_{ij})) \qquad (9)$$

where $\lambda > 0$ is a lagrange multiplier and λ is a measure for the value of a marginal increase in the resource stock.

Our main interest is in the first-order condition for E_{ij}:

$$\delta L/\delta E_{ij} = p\delta G_{ij}/\delta E_{ij} - c_{ij} + (1-\mu)(p\delta G_{ij}/\delta E_{ij} - c_{ij}) - \lambda\delta G_{ij}/\delta E_{ij} = 0 \qquad (10)$$

The optimal solution for the EU is where the marginal benefits are equal to the marginal costs. The marginal benefits consist of the marginal resource rent ($p\delta G_{ij}/\delta E_{ij}$ - c_{ij}) and the value of the marginal tax revenue $((1 - \mu)(p\delta G_{ij}/\delta E_{ij} - c_{ij}))$. The marginal costs for the EU are the effect on the resource stock of increased effort evaluated with the shadow price $(\lambda\delta G_{ij}/\delta E_{ij})$. If $E_{ij} < \underline{E}$, the EU wants the Member States to produce to a point where $p\delta G_{ij}/\delta E_{ij} – c_{ij} > 0$. Thus, the EU captures part of the production externality associated with the fishery stock. Further, it is seen that the EU wants an effort level where the marginal costs are larger than the value of the marginal tax revenue $(\lambda\delta G/\delta E_{ij} > (1 – \mu)(p\delta G/\delta E_{ij} – c_{ij})$ since $p\delta G_{ij}/\delta E_{ij} – c_{ij} > 0)$.

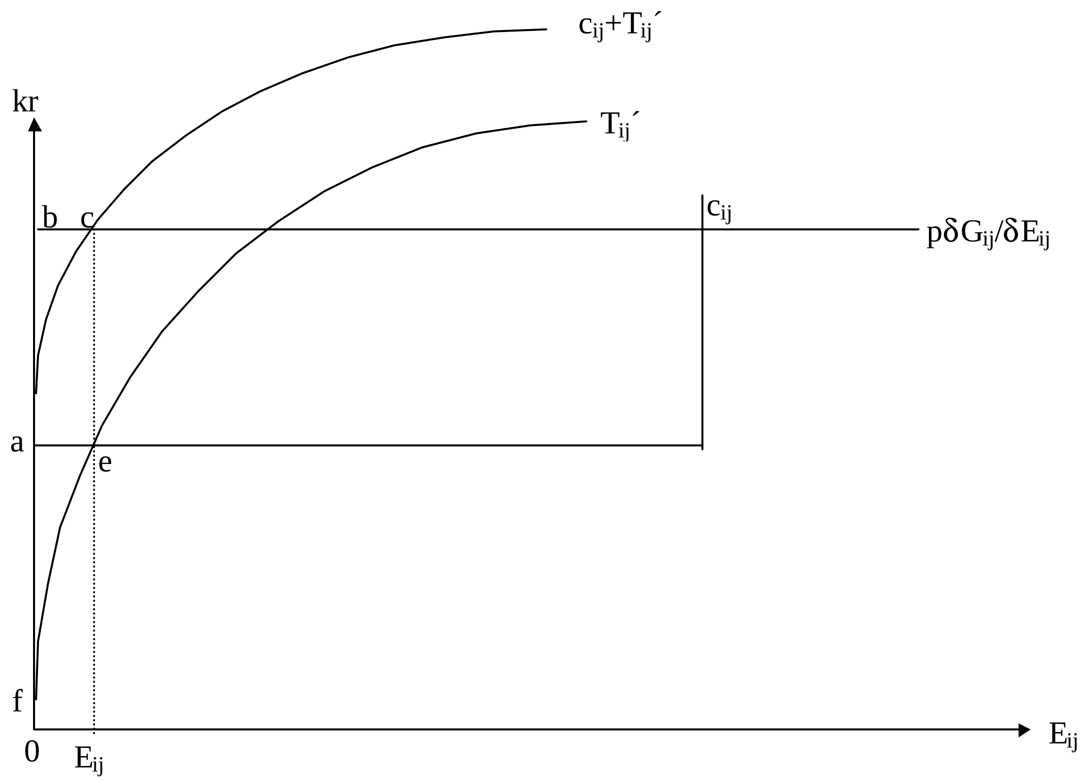
The optimal marginal tax may be found by equalizing (10) with (2). This yields:

$$T_{ij}'(E_{ij}) = – (1 – \mu)(p\delta G/\delta E_{ij} – c_{ij}) + \lambda\delta G/\delta E_{ij} \tag{11}$$

From the above we know that $\lambda\delta G/\delta E_{ij} > (1 – \mu)(p\delta G/\delta E_{ij} – c_{ij})$. Therefore the marginal tax is positive. An interpretation of this tax may be found by contrasting it with the tax that would generate a pareto optimum (the case where tax revenue is not included in the objective function and there ise no participation restriction). This would be $T_{ij}'(E_{ij}) = \lambda\delta G_{ij}/\delta E_{ij}$, which entirely captures the externality nature of the fishery stock. In this case we name the optimal effort E*. Since the EU includes tax revenue in the objective function and suffers from a fiscal illusion, the value of the marginal tax revenue must be subtracted and we would expect that $E_{ij} > E^*$. If $E_{ij} < \underline{E}$ the tax does, however, secure a welfare gain compared to the unregulated optimum, and from a normative perspective there are some benefits associated with using it.

In appendix 1 we characterize the optimal marginal tax function. Here we want to illustrate the tax function and the optimal solution. This can be done by drawing the Member States first-order condition, see figure 2.

Figure 2: The optimal level of effort under full information



Since λ is increasing in effort with a decreasing rate (appendix 1), the marginal tax function looks like $T_{ij}´$. E_{ij} is the optimal level of effort, where the value of the marginal product is equal to the marginal costs (the level of effort the fishermen would exert given the tax imposed on the Member States). The area *abce* will be equal to $OE_{ij}ef$ since the participation restriction must be satisfied.

3 A simple adverse selection model

Assume now that the EU knows that fishermen j in country i belongs to one of two types – a low cost of type 1 and high cost of type 2, with

$C_{ij2}(E) > C_{ij1}(E)$ for all E, where the subscripts 1 and 2 devote types. EU has incomplete information about the type of fishermen j, but sets a probability, π_h for h = 1, 2 to type h. Since the constant marginal costs for type 2 are higher than the constant marginal costs for type 1, single crossing property is fulfilled.

The basic incentive problem is that the low cost agent may pretend to be a high cost agent, because he can benefit from this. We assume that the EU wishes to design the tax system in such a way that there is an economic incentive for the countries to reveal the correct type of fishermen. Technically, two self-selection restrictions are included in the model.

EU's maximization problem for fishermen j in country i is:

$$\max_{E_{ij1}, E_{ij2}, x, T_{ij1}, T_{ij2}} \sum\sum\pi_1 (pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1-\mu)T_{ij1}(E_{ij1})) +$$

$$\sum\sum\pi_2(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) + (1-\mu)T_{ij2}(E_{ij2})) \qquad (12)$$

s.t.

$$F(x) - \sum\sum G_{ij1}(x, E_{ij1}) - \sum\sum G_{ij2}(x, E_{ij2}) = 0 \qquad (13)$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) - T_{ij1}(E_{ij1}) \geq 0 \qquad (14)$$

$$pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) - T_{ij2}(E_{ij2}) \geq 0 \qquad (15)$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) - T_{ij1}(E_{ij1}) \geq pG_{ij2}(x, E_{ij2}) - C_{ij1}(E_{ij2}) - T_{ij2}(E_{ij2}) \qquad (16)$$

$$pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) - T_{ij2}(E_{ij2}) \geq pG_{ij1}(x, E_{ij1}) - C_{ij2}(E_{ij1}) - T_{ij1}(E_{ij1}) \tag{17}$$

where (16) and (17) are the self-selection restrictions. They express that the Member States must have an incentive to reveal the correct type of fishermen. A remark is in place with regard to (16). It is assumed that if the Member States pretend that a low-cost fisherman is a high-cost fisherman, it must also induce a high-cost fisherman effort, induce a high-cost fisherman catch and pay a tax based on the assumption that the fisherman is high cost type. In other words it is assumed that the EU uses all the information it can gather about the fishermen when taxing the Member States.

In appendix 2 it is shown that $E_{ij1} \geq E_{ij2}$. The low cost agents are therefore allowed to have an effort level that is at least as large as the high cost agents. Further it is shown that type 2's participation restriction and type 1's self-selection restriction are binding. This means that:

$$pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) = T_{ij2}(E_{ij2}) \tag{18}$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + C_{ij1}(E_{ij2}) - C_{ij2}(E_{ij2}) = T_{ij1}(E_{ij1}) \tag{19}$$

Equation (18) indicates that the tax is designed in such a way that the high cost agent's surplus is exhausted. Since $C_{ij1}(E_{ij2}) - C_{ij2}(E_{ij2}) < 0$ in (19), the low cost agent receives a surplus – an information rent. The notion of information rents to the most efficient types is a well-known result – see e.g. Varian (1992).

By substituting (18) and (19) into (12), we obtain a rewritten maximization problem and we can set up a lagrange function. The first-order condition for the effort levels is:

$$\delta L/\delta E_{ij1} = \pi_1(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1} + (1 - \mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1})) - \lambda\delta G_{ij1}/\delta E_{ij1} = 0 \qquad (20)$$

$$\delta L/\delta E_{ij2} = \pi_1 (1 - \mu)(c_{ij1} - c_{ij2}) + \pi_2(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2} +$$

$$(1 - \mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2})) - \lambda\delta G_{ij2}/\delta E_{ij2} = 0 \qquad (21)$$

According to (20) the EU wishes to set the expected marginal benefit equal to expected marginal costs for type 1. The expected marginal benefits consist of the expected marginal resource rent and the marginal tax revenue. The marginal costs consist of the effect on the resource stock. Compared with full information, we see that we do not reach a full information optimum, if $\pi_1 < 1$ (compare (10) with (21)). This effect is new compared to the standard principal-agent theory, see Varian (1992), and the reason for this is a restriction on the maximation problem. Note first that we cannot conclude that $E_{ij1} > E_{ij}$ because $\pi_1 < 1$. The reason for this λ is different between the models and that λ is increasing in E (see appendix 1). Further, the optimal stock size ($\delta G_{ij1}/\delta E_{ij1} = qx$) is different between from type to type. In Jensen and Vestergaard (1999) we compare E_{ij} with E_{ij1}. Here it is argued that we must expect $E_{ji1} > E_{ij}$, since type 1 must be allowed an information rent. We note that the value of the marginal tax revenue ($(1 - \mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1})$) is less than the probability corrected marginal cost ($1/\pi_1\lambda\delta G_{ij1}/\delta E_{ij1}$), as the marginal resource rent is positive.

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 of type 2 must be corrected with $\pi_1 (1 - \mu)(c_{ij1} - c_{ij2}) < 0$, which is referred to as the marginal incentive cost. We also note that the probability corrected marginal costs is larger than the value of the marginal tax revenue:

$(\pi_1/\pi_2(1 - \mu)(c_{ij1} - c_{ij2}) + 1/\pi_2\lambda\delta G_{ij2}/\delta E_{ij2} - (1 - \mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2}) > 0)$, because the marginal resource rent is positive. Comparing the optimal level of effort, E_{ij2}, with the level of effort under full information, E_{ij}, we would expect that $E_{ij2} < E_{ij}$. This is a standard result within analyses of adverse selection, see e.g. Varian (1992).

The marginal tax may be found by equating (20) and (21) with (2):

$$T_{ij1}'(E_{ij1}) = -(1 - \mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) + 1/\pi_1\lambda\delta G_{ij1}/\delta E_{ij1} \tag{22}$$

$$T_{ij2}'(E_{ij2}) = \pi_1/\pi_2(1 - \mu)(c_{ij2} - c_{ij1}) + 1/\pi_2\lambda\delta G_{ij2}/\delta E_{ij2} - (1 - \mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2}) \tag{23}$$

It is shown above that the marginal tax revenue is less than the probability corrected marginal costs for type 1 $((1 - \mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1})) < 1/\pi_1\lambda\delta G_{ij1}/\delta E_{ij1})$. Therefore the marginal tax for type 1 is positive. In the same way it appears from (23) that T_{ij2}' is positive because the probability corrected marginal costs are larger than the value of the marginal tax revenue $(\pi_1/\pi_2(1 - \mu)(c_{ij1} - c_{ij2}) + 1/\pi_2\lambda\delta G_{ij2}/\delta E_{ij2} + (1 - \mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2}) > 0)$. Thus, the marginal tax is positive. Compared with full information the marginal tax for type 1 must be corrected with $1/\pi_1$. For type 2 we must also correct with a measure of the cost difference between types. These corrections are made for information reasons.

The marginal tax function is analyzed in appendix 1. For reasonable values of the parameters, functions and allocation of types compared to the probabilities, the tax functions look like the graphs in figures 3 and 4.

Figure 3: Optimal level of effort for type 1 under asymmetric information

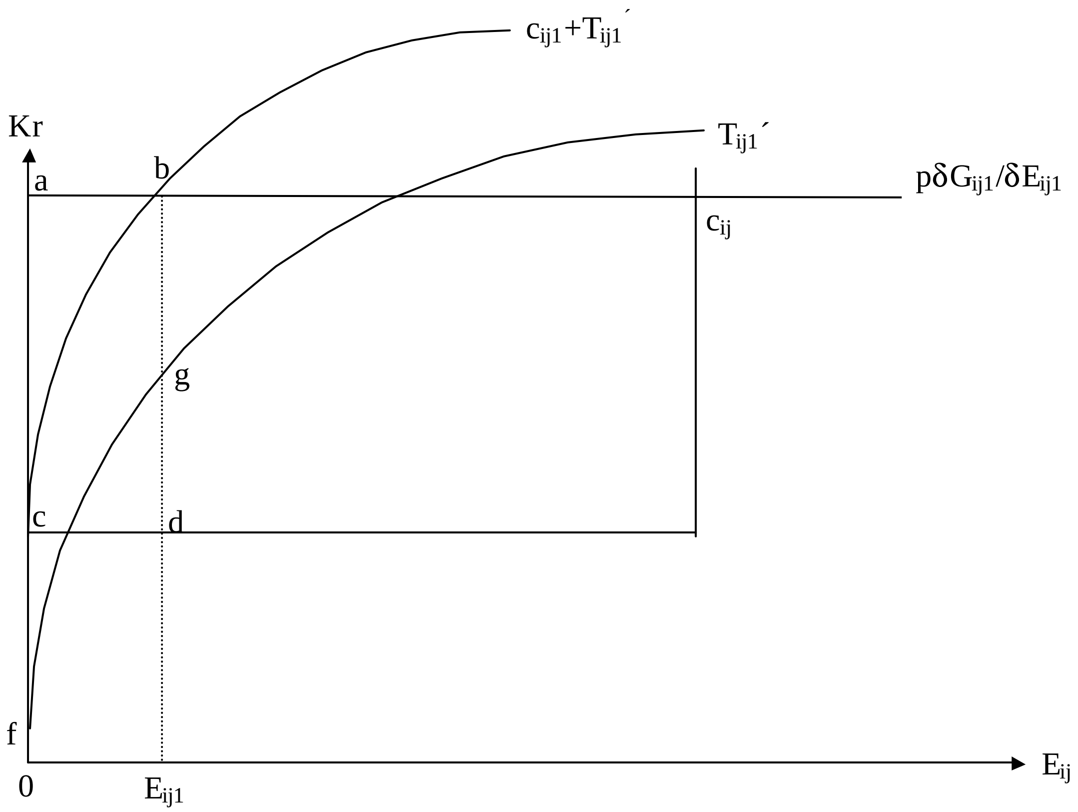
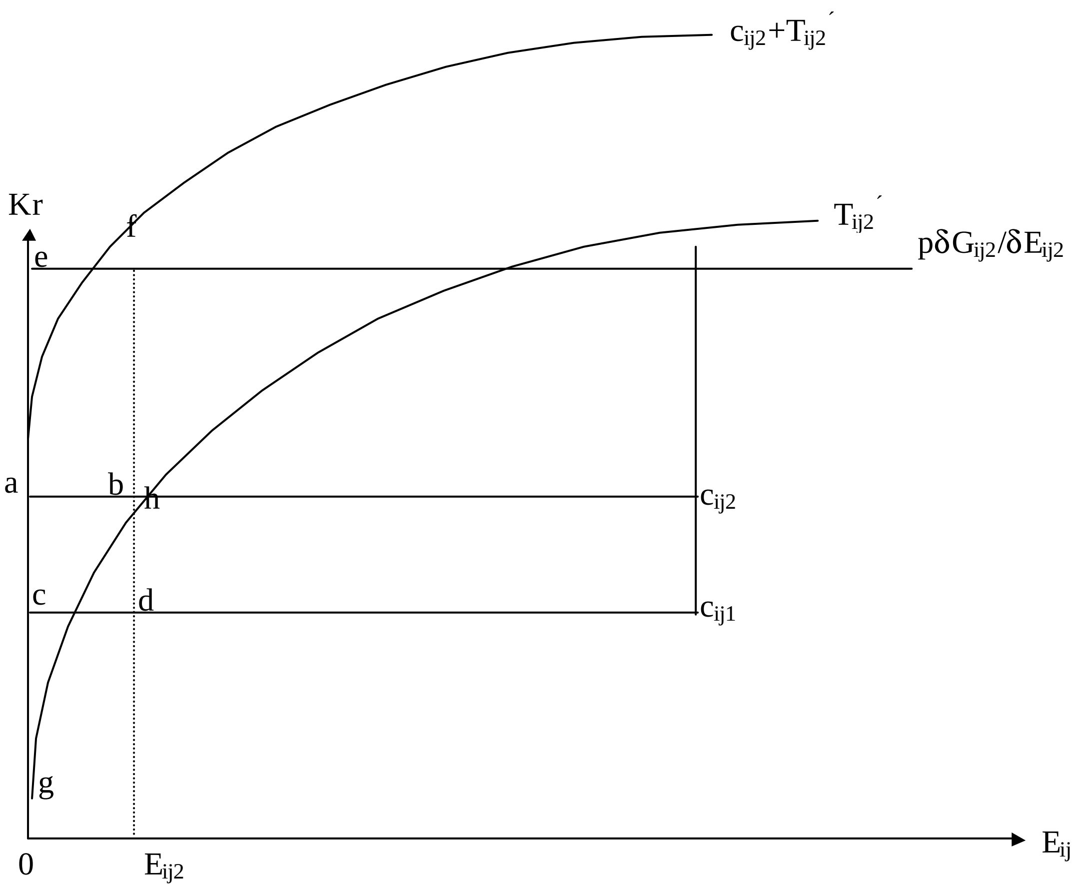


Figure 4: The optimal level of effort for type 2 under adverse selection

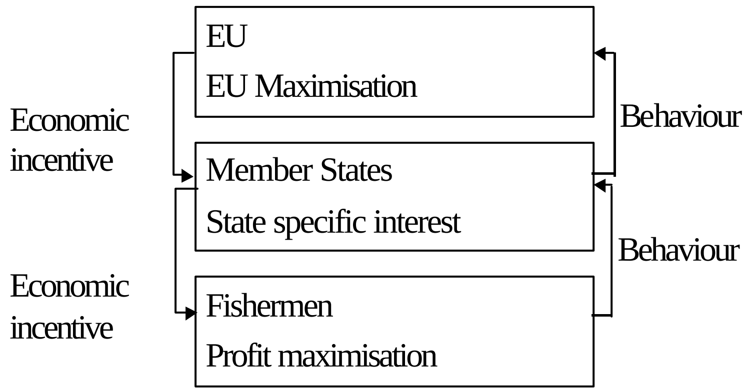


Again, the Member States first-order conditions are drawn. They induce the fishermen to deliver E_{ij1} and E_{ij2} unit of effort. In figure 3 the information rent for type 1 is *abcd* – $OfgE_{ij1}$ and the effort level is E_{ij1}. The information rent can also be seen from figure 4 as *abcd*. In figure 4 the area *abef* is equal to $OghE_{ij2}$ since the participation restriction must be satisfied.

4 A more advanced adverse selection model

We might question some of the assumptions made in the simple model. That the Member States totally disregard the resource restriction may not seem reasonable. Further, since the Member States are taxed, it must be expected that they will also tax the fishermen. One can discuss whether the Member States include the restriction. In a non-cooperative Prisoners Dilemma game, it would be a Nash equilibrium for the Member States to disregard the resource restriction. In other words it would be rationally for the Member States not to take any resource conservation measures. Another argument for the proposition that the Member States do not include the restriction is that EU already takes resource conservation measures. Because the EU includes the restriction and the Member States know that the EU includes the restriction, the Member States would not take any resource conservation measures. However, Arnason (1990) builds a fishery economic model, where individual fishermen take some resource considerations within a national regulatory framework. In other words the fishermen have in some sense altruistic preferences. This hypothesis is translated to Member States in this paper. In what follows we will therefore analyze a double principal-agent problem, see figure 5.

Figure 5: A double principal-agent model



We now allow that the Member States tax the fishermen and play part in respect to take resource conservation considerations (take into account part of the resource restriction). They wish to induce the fishermen to an optimal level of effort from the point of view of the Member States. They are, however, taxed from EU, and the EU uses their taxes to secure that the Member States regulate the fishermen to an optimal level of effort from the EU point of view. We solve the double principal-agent problem backwards – starting with the fishermen, then the Member States and finally EU. The basic question we ask is how the EU tax from section 3 must be modified? We assume that the Member States know the fishermen´s type with certainty but that EU has the information structure sketched in section 3.

The first question we encounter is how to model the fishermen. We could use a traditional open-access assumption, but choose not to do so. The reason for this is that the Member States are engaged in various entry and exit programs – e.g. the Netherlands have a system of individual transferable quotas and United Kingdom have a license system[8]. In line with the assumptions from section 2 fishermen j in country i are assumed to maximize the resource rent minus the tax paid to the Member States:

$$\max_{E_{ij}} \; pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - S_{ij}(E_{ij}) \tag{24}$$

where S_{ij} is the Member State tax. Again we imagine a non-linear, individual tax.

The first order condition is:

$$p\delta G_{ij}/\delta E_{ij} - c_{ij} - S_{ij}{}'(E_{ij}) = 0 \tag{25}$$

8 See e.g. Davidse *et al* (1997).

and the value of the marginal product is set equal to marginal costs. If they were unregulated the fishermen would choose E. If they are regulated with a marginal tax on $S_{ij}´$ in optimum, they would choose E_{ij}.

What do we assume about Member State i? In line with previous assumptions they are assumed to suffer from a fiscal illusion and include tax revenue from the fishermen in the objective function. Also, in line with the previous assumptions they include a participation restriction in the maximization problem. More important they are assumed to take some account for the resource restriction, but have state specific interests. More specifically, they want a biological and economic equilibrium – but only with respect to catches by own fisherman. Thus, if k measures the degree of fiscal illusion, Member State i is assumed to maximize:

$$\max_{E_{ij},\, x,\, S_{ij}} \sum pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - T_{ij}(E_{ij}) + (1-k)S_{ij}(E_{ij}) \tag{26}$$

s.t.

$$F(x) - \sum G_{ij}(x, E_{ij}) = 0 \tag{27}$$

$$pG_{ij}(x, E_{ij}) - C_{ij}(E_{ij}) - S_{ij}(E_{ij}) \geq 0 \tag{28}$$

Since taxes shall be as large as possible according to the benefit function, the participation restriction, (28), will always be binding. By substituting the binding participation restriction into the objective function we can set up a lagrange function. The first order condition for E_{ij} is:

$$\delta L/E_{ij} = p\delta G_{ij}/\delta E_{ij} - c_{ij} + (1-k)(p\delta G_{ij}/\delta E_{ij} - c_{ij}) - T´(E_{ij}) - m\delta G_{ij}/\delta E_{ij} = 0$$

(29)

where $m > 0$ is a lagrange multiplier and a measure for the marginal value of the fish stock evaluated from the point of view of the Member States. We will assume that $m < \lambda$, since the Member States only corrects the part of the production externality associated with their own fishermen.

According to (29) the Member States set the marginal benefit equals to marginal costs. The marginal costs consist of the marginal fish stock costs of increased effort and the marginal EU tax costs. The marginal benefit is the marginal resource rent and the value of the marginal tax revenue. Note that the marginal costs must be larger than the value of the marginal tax revenue $((1 - k)(p\delta G_{ij}/\delta E_{ij} - c_{ij}) < T'(E_{ij}) + m\delta G_{ij}/\delta E_{ij})$.

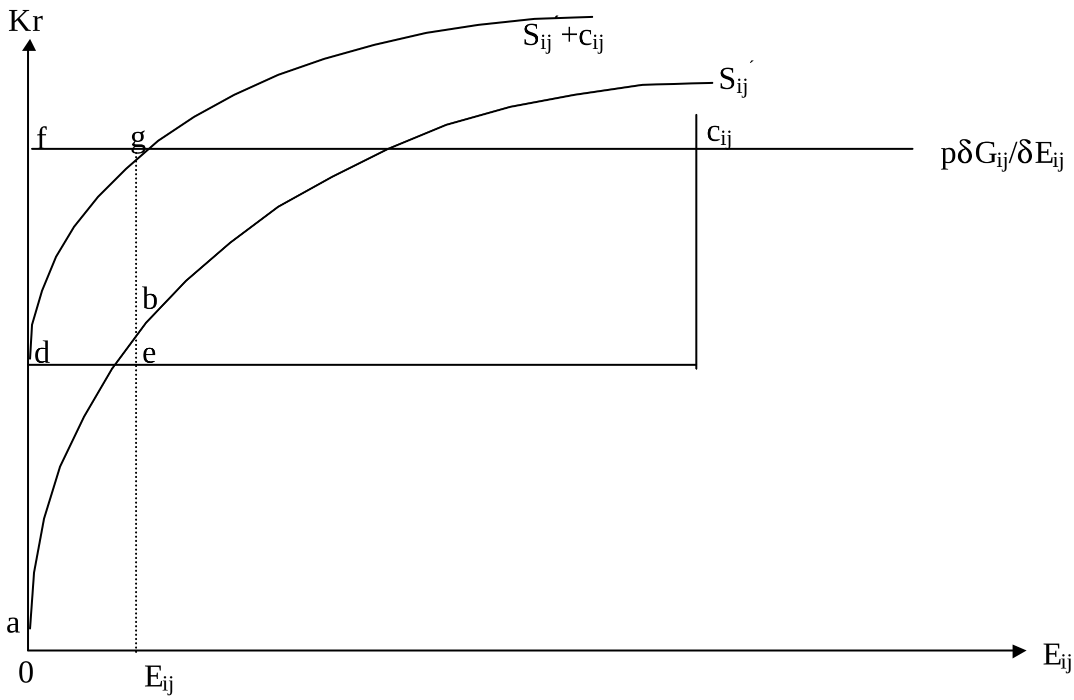
We may find the marginal Member State tax by equating (25) with (29):

$$S'(E_{ij}) = -(1 - k)(p\delta G_{ij}/\delta E_{ij} - c_{ij}) + m\delta G_{ij}/\delta E_{ij} + T_{ij}'(E_{ij}) \qquad (30)$$

Above it is shown that the marginal costs are larger than the value of the marginal tax revenue. Therefore $S_{ij}'(E_{ij}) > 0$. The marginal Member State tax consists of three components – the value of the marginal Member State tax revenue, the marginal EU tax and the marginal fish stock costs evaluated from the point of view of the Member States. In section 2 we arrived at a marginal EU tax consisting of two components – the marginal tax revenue and the marginal resource costs both evaluated from the point of view of the EU. We must expect that $k \neq \mu$ and $m \neq \lambda$, and there will be a difference between the marginal Member State tax and the marginal EU tax from section 2. From the point of view of the EU there is still a rational for taxing. Since we assume that $m < \lambda$ the Member States only solve a part of the production externality problem – the part associated with their own fishermen. Note also that the Member States canalize the whole marginal EU tax to the fishermen.

In appendix 1 the marginal tax function is characterized. It is drawn in figure 6, which sketch the fishermen´s first order condition.

Figure 6: The optimal level of effort for the Member States under full information



In figure 6 the optimum effort exerted by the fishermen is E_{ij} ($p\delta G_{ij}/\delta E_{ij} = c_{ij} + S_{ij}'$) and S_{ij} is shaped as sketched. The area $0abE_{ij}$ will be equal to the area *dfge*, since the participation restriction is fulfilled.

Now to the EU maximization problem. We retain all the assumptions from section 2 and 3 so:

$$\text{Max} \sum\sum\pi_1(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1-\mu)T_{ij1}(E_{ij1})) + \sum\sum\pi_2(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) + (1-\mu)T_{ij2}(E_{ij2})) \quad (31)$$

s.t.

$$F(x) - \sum\sum G_{ij1}(x, E_{ij1}) - \sum\sum G_{ij2}(x, E_{ij2}) = 0 \quad (32)$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1- k)(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1})) - T_{ij1}(E_{ij1}) \geq 0 \quad (33)$$

$$pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) + (1-k)(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) - T_{ij2}(E_{ij2}) \geq 0 \quad (34)$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1-k)(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1})) - T_{ij1}(E_{ij1}) \geq$$

$$pG_{ij2}(x, E_{ij2}) - C_{ij1}(E_{ij2}) + (1-k)(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) - T_{ij2}(E_{ij2}) \quad (35)$$

$$pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2}) + (1-k)(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) - T_{ij2}(E_{ij2}) \geq$$

$$pG_{ij1}(x, E_{ij1}) - C_{ij2}(E_{ij1}) + (1-k)\, p(G_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) - T_{ij1}(E_{ij1}) \quad (36)$$

As regards participation restrictions, they are, as in section 2, formulated with respect to individual fishermen. In other words the EU wants to secure the survival of each individual fisherman, and must therefore give the Member States a positive benefit for each. With regard to (35) and (36) it is, as in section 3, assumed that EU can monitor the Member State tax, the catch and the effort for the fishermen. If Member States pretend a type 2, it must e.g. tax the fishermen on basis of a type 2 cost function.

In appendix 2 it is shown that $E_{ij1} \geq E_{ij2}$. Further, it is shown that type 2's participation restriction and type 1's self-selection restriction is binding. For type 2 the Member States' benefit, which consists of the resource rent and the value of the tax revenue, is exhausted, while the Member States receive an information rent on $C_{ij2}(E_{ij2})$ - $C_{ij1}(E_{ij2})$ for type 1. The results obtained here ((34) and (35)) are the same as in section 3. Substituting the binding restrictions into the objective function yields a new maximization problem. A lagrange function can be set up and differentiating it with respect to E_{ij1} and E_{ij2} results in the following first-order conditions:

$$\delta L/\delta E_{ij1} = \pi_1(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1} + (1-\mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) +$$

$$(1-\mu)(1-k)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1})) - \lambda\delta G_{ij1}/\delta E_{ij1} = 0 \qquad (37)$$

$$\delta L/\delta E_{ij2} = \pi_1(1-\mu)(c_{ij1} - c_{ij2}) + \pi_2(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2} + (1-\mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2}) +$$

$$(1-\mu)(1-k)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2})) - \lambda\delta G_{ij2}/\delta E_{ij2} = 0 \qquad (38)$$

Compared with the analysis in section 3, there is one additional marginal benefit associated with E – the benefit of the marginal tax revenue to the Member State evaluated from the point of view of the EU. The reason for including this is that EU wishes to tax the value of the

Member State tax revenue away according to the binding self-selection and participation restrictions

The marginal tax may be calculated by equating (37) and (38) with (29):

$$T_{ij1}'(E_{ij1}) = -(1-\mu)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) - (1-\mu)(1-k)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) +$$

$$(1-k)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) + 1/\pi_1(\lambda - m)\delta G_{ij1}/\delta E_{ij1} \quad (39)$$

$$T_{ij2}'(E_{ij2}) = \pi_1/\pi_2(c_{ij2} - c_{ij1}) - (1-\mu)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2}) - (1-\mu)(1-k)(p\,\delta G_{ij2}/\delta E_{ij2} - c_{ij2})$$

$$+ (1-k)(p\delta G_{ij2}/\delta E_{ij2} - c_{ij2})) + 1/\pi_2(\lambda - m)\delta G_{ij2}/\delta E_{ij2} \quad (40)$$

Note, that T_{ij1}' and T_{ij2}' may be a marginal subsidy rather than a marginal tax, if the level of effort the Member States wish is too low compared with the level EU prefers. We will, however, assume that this is not the case – e.g. m is small, which means that the production externality that the Member States correct is not too high. There are two differences with the tax in (39) and (40) compared to the tax in section 3. First, the marginal value of the Member State tax – evaluated both from the point of view of the Member States and EU – is included. Second, EU only corrects the part of the production externality that the Member States do not correct. One basis of the marginal taxes we may also compare the effort levels in this model with the effort levels in the simple adverse selection models. If the optimal stock is identical ($\delta G_{ij1}/\delta E_{ij1} = qx$ is the same) and λ is the same for the two models the marginal tax for type 1 in this model is larger than the marginal tax in the simple adverse selection model in the case $\mu(1 - k)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1}) > 1/\pi_1 m\delta G_{ij1}/\delta E_{ij1}$.

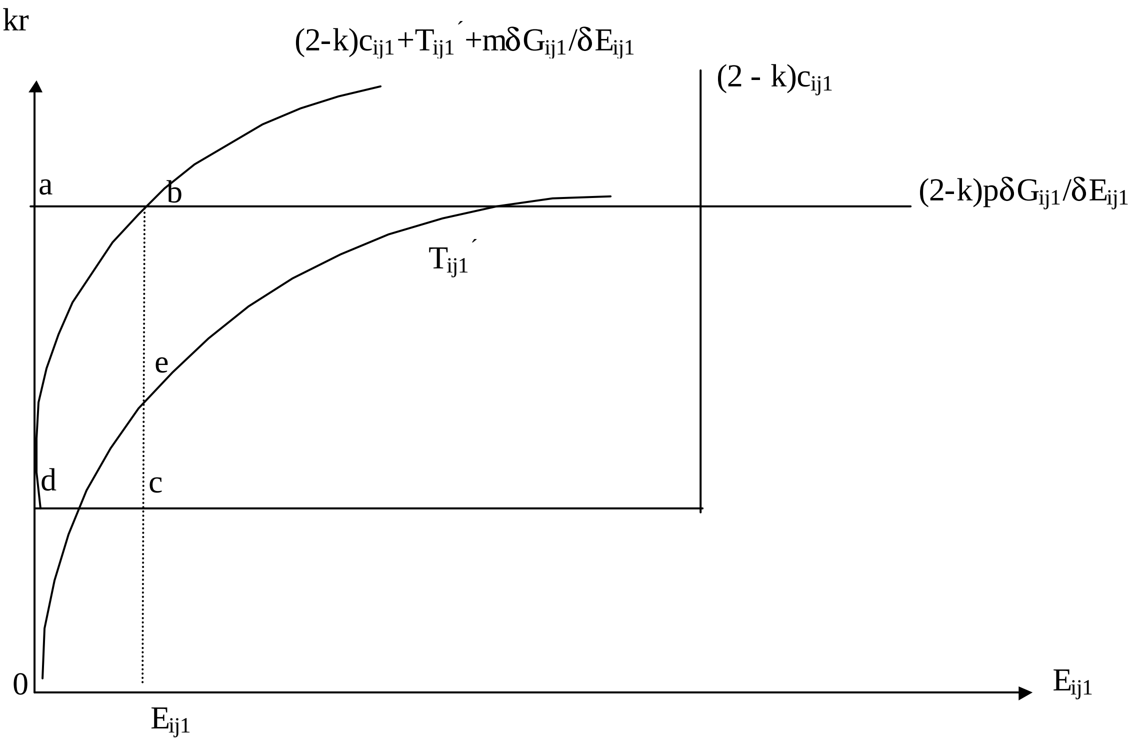
If the marginal tax is larger the effort level will be lower. $\mu(1 - k)(p\delta G_{ij1}/\delta E_{ij1} - c_{ij1})$ is the marginal costs of letting the Member States tax, and $\pi_1 m\delta G_{ij1}/\delta E_{ij1}$ is the marginal benefit of letting the Member States tax. Therefore the effort level in this model will be lower than the effort level in the simple adverse selection model if the marginal benefit of letting the Member States tax is lower than the marginal costs. The same result holds for type 2.

In appendix 1, the properties of the marginal tax functions are analyzed. The Member States first-order condition, (29), for type 1 may be written as:

$$(2 - k)p\delta G_{ij1}/\delta E_{ij1} = (2 - k)c_{ij1} + T_{ij1}{}'(E_{ij1}) + m\delta G_{ij1}/\delta E_{ij1} \qquad (41)$$

Figure 7 illustrates the first-order condition for the Member State if the fishermen are of type 1.

Figure 7: The optimal level of effort for type 1 in the advanced adverse selection model

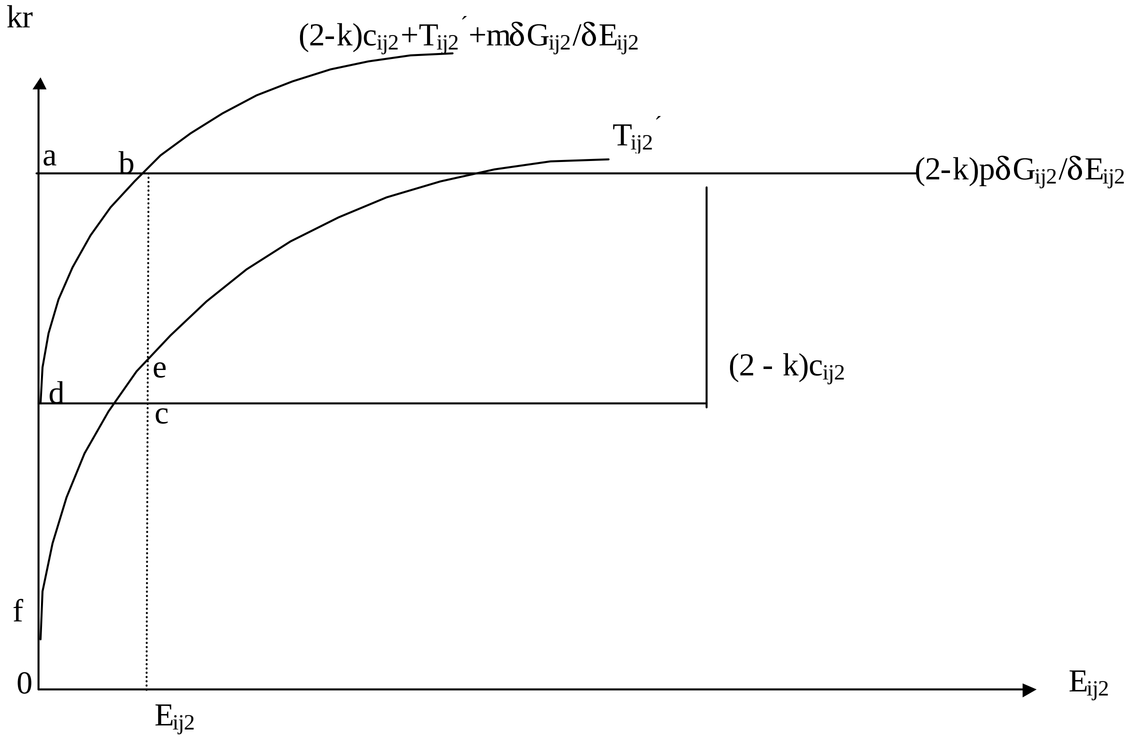


E_{ij1} is the optimum level of effort, since $(2 - k)p\delta G_{ij1}/\delta E_{ij1} = (2 - k)c_{ij1} + T_{ij1}' + m\delta G_{ij1}/\delta E_{ij1}$. The information rent is the difference between the area *abcd* and the area *$0E_{ij1}e$*.

The optimum for type 2 is drawn in figure 8. The Member States first-order condition for type 2 may be written as:

$$(2 - k)p\delta G_{ij2}/\delta E_{ij2} = (2 - k)c_{ij2} + T_{ij2}'(E_{ij2}) + m\delta G_{ij2}/\delta E_{ij2} \tag{42}$$

Figure 8: The optimal level of effort for type 2 in the advanced adverse selection model



E_{ij2} is the level of effort. Since type 2's participation restriction is fulfilled $0E_{ij2}ef = abcd$.

5 Conclusion

In this paper we have analysed an EU tax for fishery, under the assumptions that the EU suffers from a fiscal illusion and includes tax revenue in the objective function. With these assumptions the tax does not secure an optimum, but it seems that letting EU tax the Member States has at least two desirable properties: The tax can be used to correct at least a part of the production externality associated with a fishery stock and secondly: in the light of adverse selection, the tax can be used to secure correct revelation of the type of fishermen.

We have conducted a single principal-agent analysis and concluded that the EU tax will consist of three components – a marginal value of the fish stock, an information correction component and a value of the marginal tax revenue component. In a double principal-agent analysis we must also incorporate the components reflecting the value of the marginal Member State tax. But is taxing better than the existing system of TACs? Even in the light of the imperfections analysed here we believe so but there is a need for comparative evaluations of alternative regulatory regimes. The arguments for believing that a tax system is better than the TACs is as follows. The TACs are normally based on some MSY concept, and the allocation scheme of TACs to the Member States has been determined in 1983 and has not been changed since. Further the quotas do not take account for differences in efficiency between fishermen and do not lead to economic efficiency, see Clark (1990). Last TACs and quotas do not incorporate difference in information between EU, Member States and fishermen. In principal an EU tax solves all these problems.

Our analysis is an example of what Russell (1994) calls complex regulation. We have dropped some of the restrictive assumptions normally used in the discussions of regulatory regimes. Here we have skipped the traditional assumptions of perfect information. Further we have assumed a fiscal illusion and included tax revenue in the objective function. When one drops some simplifying assumptions one most accept other simplifying assumptions. In the models presented here there is no discussion of adjustment to equilibrium (we search a steady-state equilibrium) and there is no discounting rate (economic yield is maximized). Further it is assumed that the EU taxes fishery effort not output (effort is a multidimensional component). All these assumptions have been subject to a lot of criticism in the fishery economic literature, see e.g. Clark (1990). In the present context they are justified with the inclusion of asymmetric information in the analysis of fishery economic regulation. Indeed the analysis can be seen as a first attempt to include asymmetric information in the discussion of regulation of fisheries.

One can question the realism in letting EU tax the Member States on basis of individual fishermen. Remark, however, that a federal tax is sometimes discussed in the economic literature, see e.g. Segerson *et al* (1997). Further an EU tax may be reasonable within the fishery since it corrects part of the production externality problem and can be used to cover part of the budget deficit in the EU. Last, contrary to a normal resource tax the tax analyzed here does not induce any exit of fishermen because of the participation restriction.

Appendix 1: The tax function

In this appendix we characterize the properties of the tax function for all three models described in the text.

The simple model – full information

The first-order condition for x:

$$\delta L/\delta x = \sum\sum(p\delta G_{ij}/\delta x + (1-\mu)p\delta G_{ij}/\delta x) + \lambda(\delta F/\delta x - \sum\sum\delta G_{ij}/\delta x) = 0 \quad (1)$$

We note that:

$$\lambda = -\sum\sum(p\delta G_{ij}/\delta x + (1-\mu)p\delta G_{ij}/\delta x)/(F'(x) - \sum\sum\delta G_{ij}/\delta x)) \quad (2)$$

By differentiating the tax function with respect to E_{ij} we obtain (remember the properties assumed for the production function):

$$T_{ij}'' = \delta\lambda/\delta E_{ij}\, \delta G_{ij}/\delta E_{ij} \quad (3)$$

The slope of the marginal tax function depends on how the shadow price develops with E_{ij}. By differentiating λ with respect to E_{ij} we obtain:

$$\delta\lambda/\delta E_{ij} = -F'(x)(pq + (1-\mu)q)/(F'(x) - \sum\sum\delta G_{ij}/\delta x)^2 \quad (4)$$

Since $F'(x) < 0, \delta\lambda/\delta E_{ij} > 0$ and $T_{ij}'' > 0$. That the shadow price is increasing in E_{ij} seems to be a logical result, since the resource becomes more scarce as effort increases.

We will also be interested in the curvature of T_{ij}'. Differentiating (3) with respect to E_{ij} gives:

$$T_{ij}''' = \delta^2\lambda/\delta E_{ij}^2\, \delta G_{ij}/\delta E_{ij} \qquad (5)$$

and differentiating (4) with respect to E_{ij} yields:

$$\delta^2\lambda/\delta E_{ij} = -\, 2qF'(x)(pq + (1 - \mu)q)/(F'(x) - \Sigma\Sigma\delta G_{ij}/\delta x)^3 < 0 \qquad (6)$$

The implication is that the tax function looks like figure 3.

The simple model – adverse selection

The first-order condition for x is:

$$\delta L/\delta x = \Sigma\Sigma\pi 1(p\delta Gij1/\delta x + (1 - \mu)\, p\delta Gij1/\delta x) + \Sigma\Sigma\pi 2(p\delta Gij2/\delta x +$$

$$(1 - \mu)p\delta Gij2/\delta x + \lambda(F'(x) - \Sigma\Sigma\delta Gij1/\delta x - \Sigma\Sigma\delta Gij1/\delta x) = 0 \qquad (7)$$

This may be solved for λ:

$$\lambda = -(\Sigma\Sigma\pi 1(p\delta Gij1/\delta x + (1 - \mu)\, p\delta Gij1/\delta x) + \Sigma\Sigma\pi 2(p\delta Gij2/\delta x +$$

$$(1 - \mu)p\delta Gij2/\delta x)/\ \lambda(F'(x) - \Sigma\Sigma\delta Gij1/\delta x - \Sigma\Sigma\delta Gij1/\delta x) \qquad (8)$$

By differentiating T_{ij1}' with respect to E_{ij1} and T_{ij2}' with respect to E_{ij2} we obtain:

$$T_{ij1}'' = 1/\pi_1\, \delta G_{ij1}/\delta E_{ij1}\, \delta\lambda/\delta E_{ij1} \qquad (9)$$

$$T_{ij2}'' = 1/\pi_2\ \delta G_{ij2}/\delta E_{ij2}\ \delta\lambda/\delta E_{ij2} \qquad (10)$$

and by differentiating λ we obtain:

$$\delta\lambda/\delta E_{ij1} = \Sigma\Sigma(\pi_1 - \pi_2)(pq + (1 - \mu)q)\ \delta G_{ij2}/\delta x -$$

$$F'(x)\pi_1(pq + (1 - \mu)q)/(F'(x) - \Sigma\Sigma\delta G_{ij1}/\delta x - \Sigma\Sigma\delta G_{ij2}/\delta x)^2 \qquad (11)$$

$$\delta\lambda/\delta E_{ij2} = \Sigma\Sigma(\pi_2 - \pi_1)(pq + (1 - \mu)q\ )\delta G_{ij1}/\delta x -$$

$$F'(x)\pi_2(pq + (1 - \mu)q)/(F'(x) - \Sigma\Sigma\delta G_{ij1}/\delta x - \Sigma\Sigma\delta G_{ij2}/\delta x))^2 \qquad (12)$$

For reasonable π_1, π_2, $\delta G_{ij1}/\delta x$, $\delta G_{ij2}/\delta x$ and $F'(x)$ we would expect the shadow price to increase with E for both types and therefore that the marginal tax function is increasing with E. If, however, π_1 is large, $\Sigma\Sigma\delta G_{ij2}/\delta x$ is large and $F'(x)$ is small it is possible T_{ij1}' will be negatively sloped. The reason for this adverse effect is that there are a lot more type 2´s than expected.

By differentiating (9) and (10) once more we obtain:

$$T_{ij1}''' = 1/\pi_1\ \delta G_{ij1}/\delta E_{ij1}\ \delta^2\lambda/\delta E_{ij1}^2 \qquad (13)$$

$$T_{ij2}''' = 1/\pi_2\ \delta G_{ij2}/\delta E_{ij2}\ \delta^2\lambda/\delta E_{ij2}^2 \qquad (14)$$

and by differentiating (11) and (12) once more we obtain:

$$\delta^2\lambda/\delta E_{ij1}^2 = -\ (\Sigma\Sigma(\pi_1 - \pi_2)(pq + (1 - \mu)q)\ \delta G_{ij2}/\delta x$$

$$F'(x)\pi_1(pq + (1 - \mu)q)q/(F'(x) - \sum\sum\delta G_{ij1}/\delta x - \sum\sum\delta G_{ij2}/\delta x)^3 \qquad (15)$$

$$\delta^2\lambda/\delta E_{ij2}{}^2 =- (\sum\sum(\pi_2 - \pi_1)(pq + (1 - \mu)q\ )\delta G_{ij1}/\delta x$$

$$F'(x)\pi_2(pq + (1 - \mu)q)q/(F'(x) - \sum\sum\delta G_{ij1}/\delta x - \sum\sum\delta G_{ij2}/\delta x)^3 \qquad (16)$$

and if the parameter is such that T_{ij1}'', $T_{ij2}'' > 0$, $\delta^2\lambda/\delta E_{ij1}{}^2$, $\delta^2\lambda/\delta E_{ij2}{}^2 < 0$ and T_{ij1}''', $T_{ij2}''' < 0$. The implication of this is that the tax function looks like the graph in figure 3 and 4.

c. The advanced model

Here we will distinguish between:

The Member State tax

2. The EU tax

c.1. The Member State tax

The first-order condition with respect to x is:

$$\delta L/\delta x = \sum(p\delta G_{ij}/\delta x + (1 - k)p\delta G_{ij}/\delta x) + m(F'(x) - \sum\delta G_{ij}/\delta x) = 0 \qquad (17)$$

Solving for m gives:

$$m = -(\sum p\delta G_{ij}/\delta x + (1 - k)p\delta G_{ij}/\delta x)/\ (F'(x) - \sum\delta G_{ij}/\delta x) \qquad (18)$$

From (30) in section 4 we obtain:

$$S''(E_{ij}) = \delta m/\delta E_{ij}\ \delta G_{ij}/\delta E_{ij} + T''(E_{ij}) \tag{19}$$

Assume for a moment that $T''(E_{ij}) > 0$. Differentiating (18) with respect to E_{ij} we obtain:

$$\delta m/\delta E_{ij} = -\,F'(x)(pq + (1 - k)q)/(F'(x) - \sum Gij(x, E_{ij}))^2 > 0 \tag{20}$$

Therefore $S''(E_{ij}) > 0$. By differentiating once more we obtain:

$$S'''(E_{ij}) = \delta^2 m/\delta E_{ij}^2\ \delta G_{ij}/\delta E_{ij} + T_{ij}'''(E_{ij}) \tag{21}$$

Assume that $T_{ij}''' < 0$. Differentiating (19) once more we obtain:

$$\delta^2 m/\delta E_{ij}^2 = -\,(F'(x)(pq + (1 - k)q)q)/(F'(x) - \sum G_{ij}(x, E_{ij}))^3 < 0 \tag{22}$$

Therefore $S'''(E_{ij}) < 0$.

c. 2. The EU tax

The first-order condition for x is:

$$\delta L/\delta x = \sum\sum\pi_1(p\delta G_{ij1}/\delta x + (1 - \mu)p\delta G_{ij1}/\delta x + (1 - \mu)(1 - k)(p\delta G_{ij1}/\delta x)) +$$

$$\sum\sum\pi_2(p\delta G_{ij2}/\delta x + (1 - \mu)p\delta G_{ij2}/\delta x + (1 - \mu)(1 - k)p\delta G_{ij2}/\delta x\ )+$$

$$\lambda(F'(x) - \sum\sum\delta G_{ijl}/\delta x - \sum\sum\delta G_{ij2}/\delta x) = 0 \tag{23}$$

By solving (23) for λ we obtain:

$$\lambda = -(\sum\sum\pi_1(p\delta G_{ij1}/\delta x + (1-\mu)p\delta G_{ij1}/\delta x + (1-\mu)(1-k)(p\delta G_{ij1}/\delta x)) +$$

$$\sum\sum\pi_2(p\delta G_{ij2}/\delta x + (1-\mu)p\delta G_{ij2}/\delta x + (1-\mu)(1-k)p\delta G_{ij2}/\delta x)/$$

$$(F'(x) - \sum\sum\delta G_{ijl}/\delta x - \sum\sum\delta G_{ij2}/\delta x) \tag{24}$$

and again λ is a measure for the value of the resource stock.

By differentiating the tax functions we obtain:

$$T_{ij1}'' = 1/\pi_1(\delta\lambda/\delta E_{ij1} - \delta m/\delta E_{ij1})\delta G_{ij1}/\delta E_{ij1} \tag{25}$$

$$T_{ij2}'' = 1/\pi_2(\delta\lambda/\delta E_{ij2} - \delta m/\delta E_{ij2})\delta G_{ij1}/\delta E_{ij2} \tag{26}$$

$$T_{ij1}''' = 1/\pi_1(\delta^2\lambda/\delta E_{ij1}^2 - \delta^2 m/\delta E_{ij1}^2)\delta G_{ij1}/\delta E_{ij1} \tag{27}$$

$$T_{ij2}''' = 1/\pi_2(\delta^2\lambda/\delta E_{ij2}^2 - \delta^2 m/\delta E_{ij2}^2)\delta G_{ij1}/\delta E_{ij1} \tag{28}$$

We will assume that T_{ij1}'', $T_{ij2}'' > 0$. This assumption seems reasonable, since we assume that $\lambda > m$. For the same reasons we would expect T_{ij1}''', $T_{ij2}''' < 0$.

Appendix 2: The restrictions

In this appendix we will characterize the results from an analysis of the incentive comparability and participation restrictions in the simple and more advanced adverse selection model.

The simple model

The two self-selection restrictions may be written as:

$$T_{ij2}(E_{ij2}) \geq pG_{ij2}(x, E_{ij2}) - pG_{ij1}(x, E_{ij1}) + T_{ij1}(E_{ij1}) +$$

$$C_{ij1}(E_{ij1}) - C_{ij1}(E_{ij2}) \qquad (1)$$

$$T_{ij2}(E_{ij2}) \leq pG_{ij2}(x, E_{ij2}) - pG_{ij1}(x, E_{ij1}) + T_{ij1}(E_{ij1}) +$$

$$C_{ij2}(E_{ij1}) - C_{ij2}(E_{ij2}) \qquad (2)$$

and (2) can only be fulfilled if:

$$C_{ij1}(E_{ij1}) - C_{ij1}(E_{ij2}) \leq C_{ij2}(E_{ij1}) - C_{ij2}(E_{ij2}) \qquad (3)$$

and because of single crossing property this can only be fulfilled if $E_{ij1} \geq E_{ij2}$.

For type 1 we have two restrictions, which may be written as:

$$T_{ij1}(E_{ij1}) \leq pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) \qquad (4)$$

$T_{ij1}(E_{ij1}) \le pG_{ij1}(x, E_{ij1}) – C_{ij1}(E_{ij1}) – (pG_{ij2}(x, E_{ij2})$ -

$C_{ij1}(E_{ij2}) – T_{ij2}(E_{ij2}))$ (5)

Since the tax must be as large as possible, according to the objective function, one of these restrictions is binding.

According to type 2's participation restriction:

$pG_{ij2}(x, E_{ij2}) – C_{ij2}(E_{ij2}) – T_{ij2}(E_{ij2}) \ge 0$ (6)

Single crossing property implies that:

$- C_{ij1}(E_{ij2}) > – C_{ij2}(E_{ij2})$ (7)

and (7) implies that:

$pG_{ij2}(x, E_{ij2}) – C_{ij2}(E_{ij2}) – T_{ij2}(E_{ij2}) > pG_{ij2}(x, E_{ij2})$ -

$C_{ij1}(E_{ij2}) – T_{ij2}(E_{ij2}) \ge 0$ (8)

0

Since the expression in brackets in (5) is positive, it must be the self-selection restriction that is binding.

Since T_{ij2} shall be as large as possible, one of type 2's restrictions must be binding. Can it be the self-selection restriction? If this is binding and we substitute the binding self-selection restriction for type 1 into the self-selection restriction for type 2, we obtain:

$C_{ij1}(E_{ij1}) – C_{ij1}(E_{ij2}) = C_{ij2}(E_{ij2}) – C_{ij2}(E_{ij1})$ (9)

(9) violates single crossing property. It must therefore be type 2's participation restriction that is binding.

The advanced model

First we show that $E_{ij1} \geq E_{ij2}$. The two self-selection restrictions may be written as:

$$T_{ij2}(E_{ij2}) \geq pG_{ij2}(x, E_{ij2}) + (1 - k)(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) +$$

$$T_{ij1}(E_{ij1}) - pG_{ij1}(x, E_{ij1}) - (1 - k)(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1})) +$$

$$C_{ij1}(E_{ij1}) - C_{ij1}(E_{ij2}) \qquad (10)$$

$$T_{ij2}(E_{ij2}) \leq pG_{ij2}(x, E_{ij2}) + (1 - k)(pG_{ij2}(x, E_{ij2}) - C_{ij2}(E_{ij2})) +$$

$$T_{ij1}(E_{ij1}) - pG_{ij1}(x, E_{ij1}) - (1 - k)(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1})) +$$

$$C_{ij2}(E_{ij1}) - C_{ij2}(E_{ij2}) \qquad (11)$$

and (11) can only be fulfilled if:

$$C_{ij1}(E_{ij1}) - C_{ij1}(E_{ij2}) \leq C_{ij2}(E_{ij1}) - C_{ij2}(E_{ij2}) \qquad (12)$$

and because of single crossing property (12) implies that $E_{ij1} \geq E_{ij2}$.

Next, we show that type 1's self-selection restriction is binding. Type 1's two self-selection restrictions may be written as:

$$T_{ij1} \leq pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1 - k)(pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1})) \qquad (13)$$

$T_{ij1} \leq pG_{ij1}(x, E_{ij1}) - C_{ij1}(E_{ij1}) + (1 - k)(pG_{ij1}(x, E_{ij1}) -$

$C_{ij1}(E_{ij1})) - (pG_{ij2}(x, E_{ij2}) - C_{ij1}(E_{ij2}) + (1 - k)(pG_{ij2}(x, E_{ij2}) -$

$C_{ij2}(E_{ij2})) - T_{ij2}(E_{ij2})$ (14)

Again one of these restrictions must be binding, since taxes shall be as large as possible. Since single crossing property is fulfilled, and type 2's participation restriction in work, the term in brackets of (14) is positive. It must therefore be type 1's self-selection restriction that is binding.

Finally, we show that type 2's participation restriction is binding. Because $T_{ij2}(E_{ij2})$ shall be as large as possible at least one of the restrictions is binding. By substituting the binding type 1 self-selection restriction into type 2's self-selection restriction we obtain (9), which violates single crossing property. It must therefore be type 2's participation restriction that is binding.

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